May 1993
ABOVE BONNEVILLE PASSAGE AND PROPAGATION COST EFFECTIVENESS ANALYSIS

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ABOVE BONNEVILLE
PASSAGE AND PROPAGATION
COST EFFECTIVENESS ANALYSIS

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COST-EFFECTIVENESS ANALYSIS

by Charles M. Paulsen, Jeffrey B. Hyman, and KrisWemstedt

EXECUTIVE SUMMARY

Resources for the Future has been working with the Bonneville Power Administration since 1984 to integrate biological and economic information to assist in the Pacific Northwest's Fish and Wildlife Program planning efforts. Our charge is to develop analytical tools that can contribute to the goal of a justifiable and accountable decision-making process. Over the last two years, we have developed several models to evaluate the cost-effectiveness of alternative strategies to mitigate hydrosystem impacts on salmon and steelhead, and applied these models to areas of the Columbia River Basin. Our latest application evaluates the cost-effectiveness of proposed strategies that target mainstem survival (e.g., predator control, increases in water velocity) and subbasin propagation (e.g., habitat improvements, screening, hatchery production increases) for chinook salmon and steelhead stocks, in the portion of the Columbia Basin bounded by Bonneville, Chief Joseph, Dworshak, and Hells Canyon dams. At its core the analysis primarily considers financial cost and biological effectiveness, but we have included other attributes which may be of concern to the region.

Planning documents written under the auspices of the Columbia Basin Fish and Wildlife Authority supplied the biological and utilization objectives for the 79 chinook and steelhead stocks that we included in our cost-effectiveness analysis. From the regional planning documents, we also identified approximately 120 propagation actions with sufficient biological and cost data for evaluation. We combined these actions with eight different passage strategies and five possible terminal harvest rates to yield a set of alternatives that includes all possible combinations of passage and propagation actions and harvest rates. We then used an optimization model that simulates the life cycle of chinook salmon and steelhead to identify cost-effective passage/propagation/harvest alternatives for meeting the desired objectives.

Although the conclusions from our analysis are only suggestive, due to the great deal of uncertainty about the efficacy of recovery actions and the life history parameters of salmonids, our results offer a number of interesting points. First, it appears that no strategy can meet all of the goals of the subbasin planners as presented in the subbasin plans. Over fifteen percent of the stocks considered never met the harvest and spawning goals simultaneously. This suggests that the planners set untealistically high goals in some of the subbasins, given the universe of propagation actions for each stock.

Second. the system-wide, least-cost strategies identified at various levels of spawning escapement and terminal harvest consistently include passage scenarios which maintain current flows. Even with pessimistic assumptions about transportation survival and bypass efficiency, flow augmentation does not appear to be a cost-effective passage option. This result prevails because: (1) any passage option generally is the most expensive single item in most system-wide strategies; (2) flows above current (1989-91) conditions ate a very expensive passage option: and (3) the estimated effectiveness of flow for increasing adult returns is low in comparison with the estimated effectiveness of other available options, including propagation actions and other downstream passage measures. Many in the region claim that flow augmentation or drawdowns are necessary measures. Our results suggest that such efforts may not be cost-etiective. This, in turn, leads us to argue forcefully for a comprehensive biological research program on the relationship between flows and downstream survival

Third, lowering the acceptable level of genetic risk introduced by hatchery plantings in wild stocks makes the subbasin escapement and terminal harvest objectives unattainable for several stocks, even with reduced objectives. If we ignore the genetic risk constraint for just these stocks and impose it on all other stocks, the overall, system-wide, least-cost alternative is the same as the alternative identified in the scenario without the genetic risk constraint. This result may change, however, if genetic risk is defined mote stringently than in our analysis, as may happen when the NPPC produces final guidelines on genetic risk.

Finally, the set of preferred subbasin propagation actions identified in the subbasin plans differs from the set of preferred actions identified in our cost-effectiveness analysis. Although a considerable overlap exists between the two sets of actions, the planner-identified set contains more propagation actions and costs more money. The subbasin plans did not include passage enhancements, so the difference in the two sets of preferred propagation actions rests on the improved passage survival that we include in our simulations. This suggests that any analysis which does not adopt a systems framework, and fails to include potential survival increases at every stage in the salmonid life cycle, risks missing fish enhancement and/or cost-saving opportunities.

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PREFACE

Congressional passage of the Pacific Northwest Electric Power Planning and Conservation Act1 in 1980 ushered in a new era in natural resource conservation in the Pacific Northwest. The Act established the Northwest Power Planning Council, composed of two members from each of the four northwestern states (Idaho, Montana, Oregon, and Washington), and gave the Council the responsibility to develop programs for regional power planning, electricity conservation, and mitigating the effects of hydropower development and operation on fish and wildlife in the Columbia River Basin. The responsibility for implementing many of the power, conservation, and mitigation programs lies with the Bonneville Power Administration (BPA) and other federal agencies with hydro or power responsibilities in the region.

As the planning and implementation of alternative mitigation and protection measures has proceeded, questions about the costs, effectiveness, and justification of these measures have become increasingly complex. Since 1984, Resources for the Future (RFF) has been working with BPA and other regional entities to address this complexity and develop methodological tools and data that can be used to evaluate the biological and financial implication of the alternative measures. This document reports on our system-wide cost-effectiveness analysis of the mitigation and protection efforts for nearly eighty steelhead and chinook salmon stocks throughout the Columbia Basin. Although the analysis is the culmination of a multi-year research effort, it is but one step in the biological and financial evaluation. Ongoing and planned additional analyses include work on endangered salmon stocks, the dynamics of salmon populations and mitigation planning, and monitoring issues.

Our debts to others, both in the region and at RFF, for their assistance in the above-Bonneville, system-wide cost-effectiveness analysis are many. Many of these debts will go unrecognized here, although this in no way indicates a lack of appreciation for the help that we

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⌐ 16 U.S.C. **§§839-839h** (1982 and Supp. II 1984)

CHAPTER 1
AN OVERVIEW OF SALMON AND STEELHEAD MITIGATION IN THE COLUMBIA BASIN

INTRODUCTION

In the last one-hundred years, annual returns of adult salmon and steelhead to the Columbia River and its tributaries have declined by as much as eighty percent. Some salmon stocks[1] already are extinct. In the last several years alone, one stock of sockeye salmon has been declared endangered and two stocks of chinook salmon have been declared threatened under the federal Endangered Species Act. The American Fisheries Society has identified more than seventy additional Columbia Basin stocks as being of concern (Nehlsen. Williams, and Lichatowich, 1991).

A number of activities such as logging, mining, and agriculture have contributed to the decline of the Columbia salmon runs, by degrading salmon habitat or water quality or by removing water critical for salmon survival. Additionally, the construction of dams and development of reservoirs for power production, recreation, irrigation, and flood control have blocked off or flooded spawning and rearing habitat, and made upstream and downstream migrations more difficult on the lower-Snake and mid-and lower-Columbia rivers. Commercial and recreational fishing also have significantly reduced .salmon populations.

Efforts to rebuild the salmon stocks have been underway for more than a half-century. These efforts currently include habitat improvement, flow augmentation, transportation of juvenile salmon, predator control, hatchery production, installation of bypass facilities at dam sites, and irrigation diversion screening. Individuals and organizations throughout the region have proposed extensions of these efforts as well as additional actions, and regional entities charged with designing, funding, and implementing protection programs, such as the Northwest Power

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[1] **Salmon** that spawn in a particular location in the river system in a particular season that generally do not interbreed with 1) salmon that breed in other locations, or 2) salmon from the same location that breed in other seasons, constitute separate stocks. Each species of salmon can have multiple stocks.

Planning Council (NPPC) and the Bonneville Power Administration (BPA), are continually in the process of reviewing these proposals and deciding what package of actions to implement

Resources for the Future (RFF) is currently assisting BPA and the region in an evaluation of the biological and economic tradeoffs among alternative mitigation and recovery actions.[2] Our aim is to support fish and wildlife planning in the Columbia Basin. This document reports on our system-wide cost-effectiveness analysis of proposed mitigation and recovery strategies designed to increase the abundances of Columbia Basin salmon and steelhead populations.

In this chapter, we fitst provide a brief biological background to salmon and steelhead populations in the Columbia Basin. We continue with a discussion of the problems that Columbia Basin salmon and steelbead populations face. We then briefly examine recovery planning efforts for salmonids in the basin. We next present au overview of our research effort to assist the recovery planning efforts. The final section of this chapter lays out the chapter by chapter plan of thisreport.

BIOLOGICAL BACKGROUND

The mcovety efforts in the Columbia Basin arc concerned with a number of anadromous salmonids species such as sockeye salmon, coho salmon, chinook salmon, and steelhead trout, as well as resident fish such as kokanec salmon, white sturgeon (biologically anadromous), bull trout, and westslope cutthroat trout. We address two of the anadromous species in our analysis: chinook salmon and steelhead. In this section, we provide background on the life cycle and population trends of these two species.

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[2] In this document, we use the words *mitigation* and recovery loosely. In a formal sense, recovery refers to actions or planning related to stocks listed under the Endangered Species Act, for which a criterion for recovery has been established (*i.e.,* a criterion which signifies that the stock can be taken off of the endangered species list). *Mitigation* refers to a general class of actions or planning efforts related to the region's obligation to alleviate or compensate for the effects of hydropower development and operation on fish and wildlife in the Columbia River basin (Kneese, et al., 1988). Although their formal definitions differ, we generally use recovery and *mitigution* interchangeably. Other terms used in the region to signify efforts to protect fish include *rebuilding* and *restoration.*

Salmon and Steelhead Life Cycle

One of the main features that broadly distinguishes salmonids stocks is the timing of their life-cycle stages. Table 1.1 summarizes the general differences in the timing of various life stages for summer steelhead and spring, summer, and fall chinook salmon.   Hatching of fry takes place during late winter or early spring for all populations. Fall chinook and mid-Columbia summer chinook migrate downriver **during** their first year of life, after a brief period of rearing. Spring chinook and Snake River summer chinook migrate downriver during their second year after overwintering in the subbasin. Summer steelhead generally remain in the subbasin for two or three winters before leaving for the ocean. All stocks spend one to four years in the ocean, some migrating as far as Alaska (e.g., fall chinook), before returning to the Columbia River. They then return upriver, most often to the subbasin and even to the river of their birth. although some straying occurs. After a holding period, the adults spawn and usually die (a small percentage of steelhead have more than one spawning migration).

Recent Population Trends

In a recent study, Pratt and Chapman (1989) estimated trends in salmon and steelhead returns to the Columbia River over the period from the late 1970's to the late 1980's. We cite here their estimated run size trends based on 3-year running medians, for the major runs above Bonneville **dam.** The run size of upriver summer steelhead (Oncorhynchus mykiss) more than doubled from **about** 120,000 fish in 1979 to 300,000 fish in 1988. Chinook salmon *(Oncorhynchus tshawytscha)* mostly decreased in tributaries above Bonneville dam, except for mid-Columbia bright fall chinook. Upriver spring and summer chinook decreased from **about** 125,000 and 60,000 in 1979 to about 100,000 and 40,000 in 1987, respectively. Moreover, the Snake River runs of spring, summer, and fall chinook were recently declared threatened under the federal Endangered Species Act (the Snake river sockeye have been declared endangered under the federal Endangered Species Act). Current runs of upriver bright falls, most of which come

TABLE 1.1
A General Comparison of Timing of the Life-Cyde Stages of
Natural Upriver* Chinook Salmon and Summer Steelhead

Life Stage	Spring Chinook	Snake River Summer Chinook	Upper Columbia Summer Chinook	Fall Chinook	Summer Steelhead
Fry Emergence	Jan.-March	April-May	March-April	March-May	June-Sept.
Downstream Migration	March-June age 1	Mach-April age 1	June-August age 0	June-August age 0	April-May age 2
Return to Bonn. Dam	April-May age 4-5	June-July age 4-5	June-July age 4-5	August-October age 4-5	June-September age 4-5
Spawning	August-Sept. age 4-5	September age 4-5	Sept.-Nov. age 4-5	Nov.-Dec. age 4-5	March-May age 5-6

*above Bonneville Dam

from the Hanford Reach area, are on the order of 400,000 fish, up from about 200,000 in the early 1980's.

One should interpret these trends cautiously, for two reasons. First, trend estimates include both natural and hatchery-bred fish. Therefore, an infusion of hatchery fish may mask a precipitous decline in the natural component of the run. For example, natural fish made up . . irtually the entire annual run of upriver spring chinook during the 1950's (about 200,000 fish), whereas only about 35% of recent production (about 100,000 returns) is composed of natural fish. Indeed, many people express concern about these shifts in run composition. Second, there is no unique way to estimate a trend in run size. The data and statistic used to define a trend depend on the data at hand and the questions of interest.

PROBLEMS FOR SALMON

The downward trends for upriver salmon have not started only recently; salmon runs in the Columbia Basin have suffered a marked decline over the past one hundred and fifty years. Estimates from the available data suggest that even before the construction of Bonneville and Rock Island dams in the 193Os, the runs had already declined by fifty percent or more from their pre-European levels, and the total run size has since continued to edge downward to a level of perhaps 1 S-2.5 million fish today. Hatchery fish constitute eighty percent of the total. (Pratt and Chapman, 1989; NPPC, 1987; NPPC, 199lb).

Due to the scale of the Columbia River system and uncertainties associated with important components of the salmon life cycle, it is difficult to make definitive statements about the precise quantitative effects of the various causes of the decline.[3] Nonetheless, it is likely that five major factors have contributed to the decline of salmonids populations. These factors are dam construction and operation, reservoir impoundments, harvest, habitat degradation, and hatchery programs.

[3] Kacyzynski and Palmisano (1992) provide a recent overview of management **and** environmental factors which contributed to the decline of anadromous stocks in Oregon waters.

Dam Construcion and operation

In the middle and late 1930s several large dams and powerhouses were created on the mainstem of the Columbia River partly for the purpose of providing employment and other economic stimuli during the Great Depression. (Rock Island Dam, a Public Utilities District dam, was completed in 1933, and the much larger federal Bonneville and Grand Coulee Dams in 1938 and 1941, respectively.) During and after World War ll, demand for electricity in tbe Pacific Northwest grew steadily and rapidly until the middle 1970's and federal hydropower development occurred simultaneously on a very large scale. The system of **federal** dams in the region came to be known as the Federal Columbia River Power System. At present it consists of 31 projects on the Columbia and Snake rivers with total installed capacity of 19.350 megawatts and over 20 million acre-feet of storage capacity.[4] In addition, the region has built a number of large public and private utility hydroelectric dams and federal and state flood control dams. (See Figure 1.1 for a schematic map of the region.)

The impacts of the dams proper, as distinct from the impoundments behind them, take two forms. First, the storage **dams,**[5] in particular Chief Joseph and Hells Canyon, present absolute barriers to upstream fish migration currently, since spawners migrating upstream cannot get over or around them. Their construction eliminated access for spawners to over 30 percent of the pre-dam **anadromous** habitat (stream miles); absent construction of immensely costly fish ladders, those areas will remain inacessible for the foreseeable future (NPPC, 1986).

Second, the run-of-river dams (from Bonneville to Wells on the Columbii and Ice Harbor to Lower Granite on the Snake) present other problems The most obvious is that juvenile salmon migrating downstream to the ocean (smolts) must pass either through the turbines or over the

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[4] A city the size of Seattle requires about 1,000 megawatts.

[5] A storage dam allows dam operators to adjust the natural flow regime of the river to conform to river use needs, because such a dam permits the storage of large volumes of water. A run-of-river dam, in contrast, possesses only a limited ability to adjust flows, since it creates only a small storage pool and thus must allow water to flow past the dam at the same rate (more or less) that water is entering the upper end of the pool.
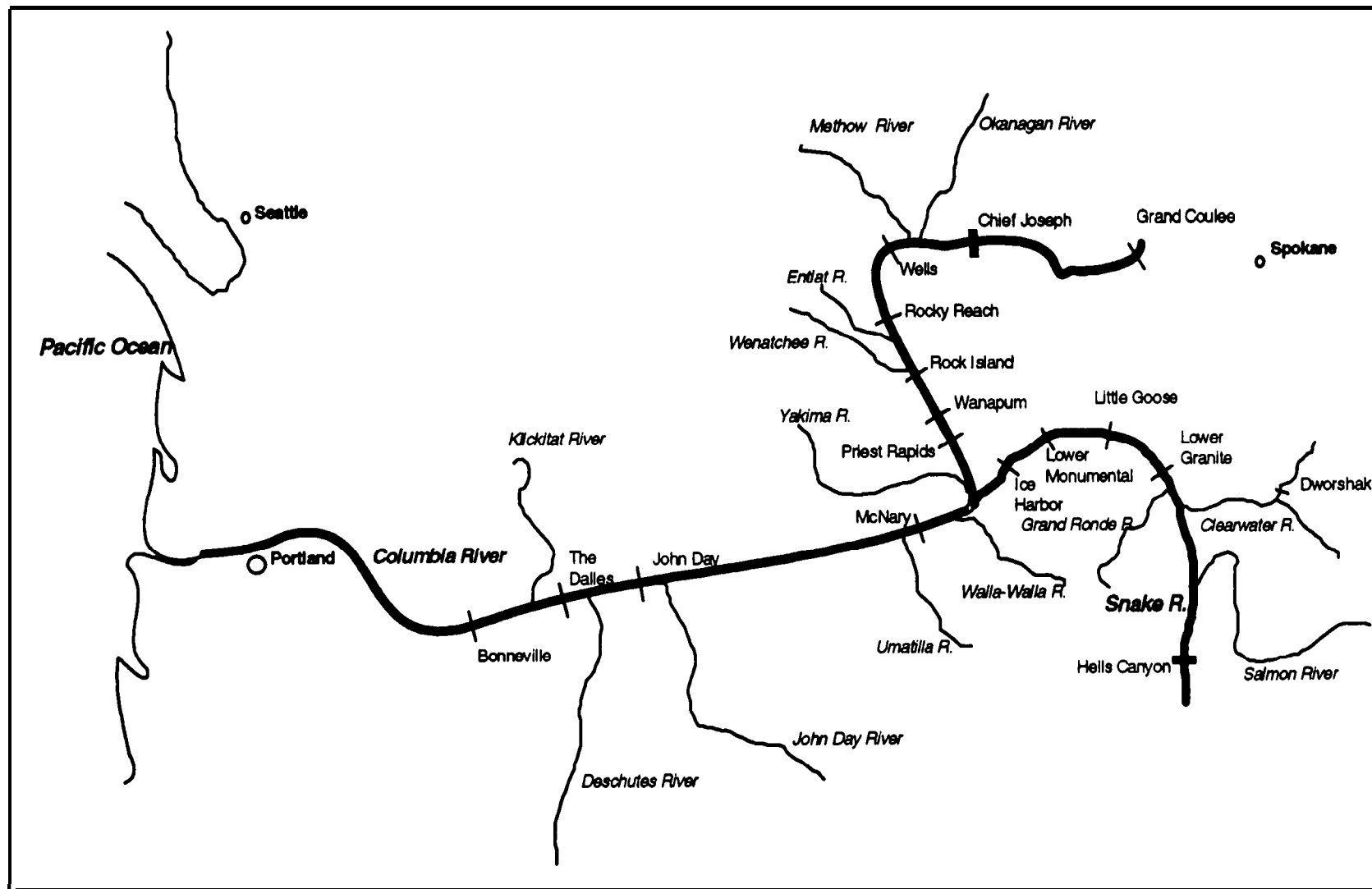
Figure 1.1. Schematic Regional Map

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spillways of the dams. In the case of turbine passage, mortality rates can be quite high, approaching thirty percent per dam under adverse conditions (NPPC, 1987: p. 12). Smolts passing over the spillways have much lower mortality rates, on the order of one to two percent per dam (Kaczynski and Palmisano, 1992: p. 62). However, the fish only move over the spillway in proportion to the flow of water. In order to induce more of the smolts to travel past each dam via its spillway, rather than the turbines, water must be touted away from the turbines and to the spillway, thereby foregoing substantial power generation. Finally, although the majority of the adults successfully traverse the fish ladders provided for them, estimates of the upstream adult passage mortality (direct and indirect) at each project approach ten percent (Kaczynski and Palmisano, 1992: 58).

Reservoir Impoundments

The impoundments created by the dams pose hazards as well. Anadromous salmonids evolved to migrate both upstream as adults and downstream as smolts in fast-moving water. Although the adults swim vigorously, the smolts are thought to spend much of their time passively floating in the current. Prior to the construction of dams, smolts migrating downstream from Idaho took approximately half the time it currently takes smolts to reach the estuary from Idaho; travel time now averages thirty to forty days, and even more in low-flow years (Giorgi, 1991). During this time, the smolts are subject to predation, and some may miss the critical window during which they can make the physiological transition from freshwater to saltwater.

The degree of mortality that results from longer travel times is a topic of much debate in the region. Some argue that except for very low flow levels, data to support the assumption that improved smolt survival will result from decreased travel times arc limited (Giorgi, 1991). Others argue that travel time is significant for smolt survival over a much wider range of flows (Columbia Basin Fish and Wildlife Authority (CBPWA), 1991a).

Harvest

In addition to being killed by the hydropower system, the fish are also harvested heavily in the ocean as they mature, and in the rivers when they return to spawn. For many stocks, our analysis of coded wire tag (CWT) data suggests that commercial and sport fisheries may harvest more than 80 percent of the fish surviving to adulthood. The proportion of the adults harvested varies widely among species and stocks; for example, naturally spawned steelhead have very low harvest rates, while almost 90 percent of hatchery-spawned fall chinook may be harvested before they can return to the hatchery to spawn.

The net economic value of the commercialharvest is modest (Kneese et al., 1988, Volume I@, but many communities depend upon it and commercial fishermen are well-organized and vocal in defending their rights to a substantial share of the fish runs. In addition, Indian treaty rights entitle various tribes to fish "in their usual and accustomed places" and to take significant portions of the fish runs. These factors, combined with a considerable sport harvest, suggest that harvest will continue to be an important influence on both the size of the run (since harvested fish obviously cannot spawn) and on its composition. The latter is a problem since naturally spawning stocks (particularly those originating upriver) generally cannot withstand the same harvest rates as hatchery stocks. It is often impossible to separate hatchery and natural fish during harvest activities, so mixed-stock harvest likely has contributed to the precipitous decline in many natural stocks.

Habitat Degradation

Habitat degradation also contributes to the decline of many stocks. Erosion due to mining, timber extraction, and grazing has changed both the topography and substrate in many spawning and rearing areas. Topographically, stream beds have become more uniform, with fewer deep pools and fast-moving rapids, and more shallow, flat-water reaches. Pre-development gravel substrates have been buried in sand and silt, which smother salmon eggs and despoil habitat used by pre-smolt juveniles. In addition, stream banks have been altered by clear-cutting and

grazing, thus reducing riparian vegetation, raising water temperatures, and reducing dissolved oxygen content. Irrigation diversion dams have blocked access to spawning and rearing areas, while intake pipes draw in fish along with irrigation water and leave them stranded in fields. Finally, a process euphemistically known as dewatering results when most or all of the flows in a subbasin are withdrawn for irrigation; while many uncertainties surround salmonid management, most would agree that water is an important part of salmonid habitat.

Hatchery Management

Many researchers in the field of salmonid behavior and management believe that hatcheries may have a number of pernicious effects on natural stocks (Kacyzynski and Palmisano, 1992; Meffe, 1992 and references therein). The least controversial negative effect arises from the fact that hatchery stocks are usually more productive than natural stocks; that is, they produce more adults in generation (n+l) per adult in generation (n) than do natural stocks. Thus, they can withstand higher harvest rates than naturally spawned stocks, other things being equal. The higher productivity, combined with mixed stock harvest and a tendency by fisheries management agencies to allow high harvest rates on many hatchery stocks, likely has contributed to the decline of some natural stocks.

The second possible negative effect of hatchery programs results from the potential genetic mixing between hatchery-bred and wild fish. Such mixing may be detrimental to the wild population, especially if the introduced hatchery stock is developed from fish adapted to a different portion of the basin (NPPC, 1992; CBFWA, 1991b). Extensive mixing may dilute the genotype of the natural stock to the point where it has trouble surviving in its original subbasin. Additionally, the risk of extinction for both the hatchery and natural stock may increase in the event that environmental changes require the "lost" genetic diversity for the stocks' survival.

Two other possible negative effect derive from short-term interactions between hatchery and wild stocks. Hatchery stocks, when released into the wild as pre-smolt juveniles, generally feed inefficiently and aggressively. When competing for food in areas with natural populations,

their behavior may be detrimental to the natural populations. Furthermore, many biologists express a concern that hatchery stocks may introduce diseases such as bacterial kidney disease (BKD) and infectious hepatitic necrosis (IHN) into naturally spawning populations.

MITIGATION PLANNING IN THE COLUMBIA BASIN

The federal Pacific Northwest Electric Power Planning and Conservation Act of 1980[6] created the Northwest Power Planning Council (NPPC) and gave it the responsibility for developing a program to mitigate the effects on fish and wildlife of hydropower development in the Columbia Basin. The Northwest Power Act specifies that the NPPC shall include in the program measures which are based on the "best available scientific knowledge" and which utilize, "where equally effective means of achieving the same sound biological objective exists, the alternative with the minimum economic cost." Federal agencies charged with implementing the NPPC's Fish and Wildlife Programs include BPA, the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the Federal Energy Regulatory Commission.

The Fish and Wildlife Program developed by the NPPC stresses a system-wide approach to rebuilding salmon and steelhead runs. It provides plans for the Columbia Basin as a whole as well as for the individual subbasins, and attempts to integrate improvements in fish production, mainstem fish passage, and harvest management. The following two subsections discuss the goals and objectives of the NPPC Fish and Wildlife Program and the types of management actions available to help meet these goals and objectives.

NPPC Goals and Objectives

The NPPC has established a number of general goals for salmon and steelhead (NPPC, 1987). The first of these is the goal of doubling the size of the basin-wide run. As part of that

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[6] 16 USC 839. The 1980 Act, generally referred to as the Northwest Power Act, gives the NPPC the responsibility to develop programs for power planning and electricity conservation. The NPPC consists of two representatives appointed by the governor from each of the Pacific Northwest states (Washington, Oregon, Idaho, and Montana).

goal, the NPPC has accorded priority to the runs above Bonneville. Since the inception of the National Marine Fisheries Service listing process for Snake River salmon in April of 1990, the NPPC has accorded additional priority to Snake River sockeye and chinook stocks, which have suffered a more marked decline than other upriver runs. A related goal is to try to restore the runs by emphasizing natural production more than has been done in the past. This reflects a desire to minimize genetic risk in the restoration process, by protecting weaker stocks and decreasing the genetic mixing of hatchery and wild fish.

While these goals are certainly reasonable, they do not provide sufficient detail to be analyzed quantitatively. The thirty subbasin plans developed by the Columbia Basin Fish and Wildlife Authority (1990) are important in this regard, since they establish specific, stock-by-stock numeric objectives, expressed in terms of subbasin harvest and spawning escapement for each stock above Bonneville Dam. As the results in Chapter 5 show, the objectives are sometimes unattainable, given the menu of management actions under consideration, but they provide a useful starting point for the quantitative analysis.

Management Actions to Benefit Fish

The Pacific Northwest can take a wide variety of actions to increase fish numbers. We discuss these possible actions in the same order that we presented the problems earlier, starting with passage past dams and ending with hatchery production. Although the various actions described below can be implemented independently, their effects on the salmon depend directly on conditions elsewhere in the system, including other management actions. For example, the region can implement a downstream passage action independently of any action that influences conditions in spawning and rearing areas. However, in order to predict the number of additional fish produced by a passage action, one must know what conditions are faced by the fish in the ocean **and** in spawning and rearing areas.

Dam Passage: Actions to improve downstream passage past dams focus on helping juveniles migrating downstream to avoid the turbines. One can route smolts around the turbines

either by routing water (and fish) over the spillways, rather than through the turbines, or by screening the turbine intakes, to induce the smolts into a bypass system (see Figure 1.2). Most of the Federal dams have already been screened, and some of the currently unscreened Federal dams are scheduled for bypass installation within the next few years.

Reservoir Passage: A number of methods have been attempted or proposed to move the smolts downstream more quickly in order to increase their survival. The first method entails an increase in the volume of flows in the river during the migration season. The water budget, a special, reserved volume of water that fish and wildlife agencies and the tribes can allocate between April 15th and June 15th, augments Columbia and Snake river mainstem flows, in order to aid the passage of smolts downstream. The region has utilized the water budget since 1982, and the NPPC plans to increase spring flows even further. Another method proposed to hasten the downstream journey of juveniles involves the drawdown of particular reservoirs to pool elevations below current pool elevations. Such drawdowns will increase the velocity of the river water and thus, theoretically, the velocity of the juvenile fish. Much of the current debate over passage actions focuses on the efficacy and desirability of these reservoir drawdowns, particularly for the endangered chinook and sockeye stocks in the Snake River subbasins. A third method, used extensively since the early 1980s, is to place smelts collected in the bypass systems into barges, transport them downstream past all dams, and release them below Bonneville Dam so that they can continue their migration under their own power. A fourth, proposed method is to build a fish canal parallel to the Snake and/or Columbia River, and route collected fish into the canal, essentially transporting them in a canal instead of barges.

To reduce the mortality of smolts as they travel through the reservoirs, BPA has begun a predator control program. The program pays a reward to anglers who catch squawfish, a major predator of smelts, in order to reduce the size of the squawfish population. In 1991, it removed more than 200,000 squawfish from the Columbia Basin (BPA, 1992).

Harvest Management: If the salmonids smolts survive their migration to the ocean, commercial, sport, and tribal harvesting together remove a large percentage of the fish surviving
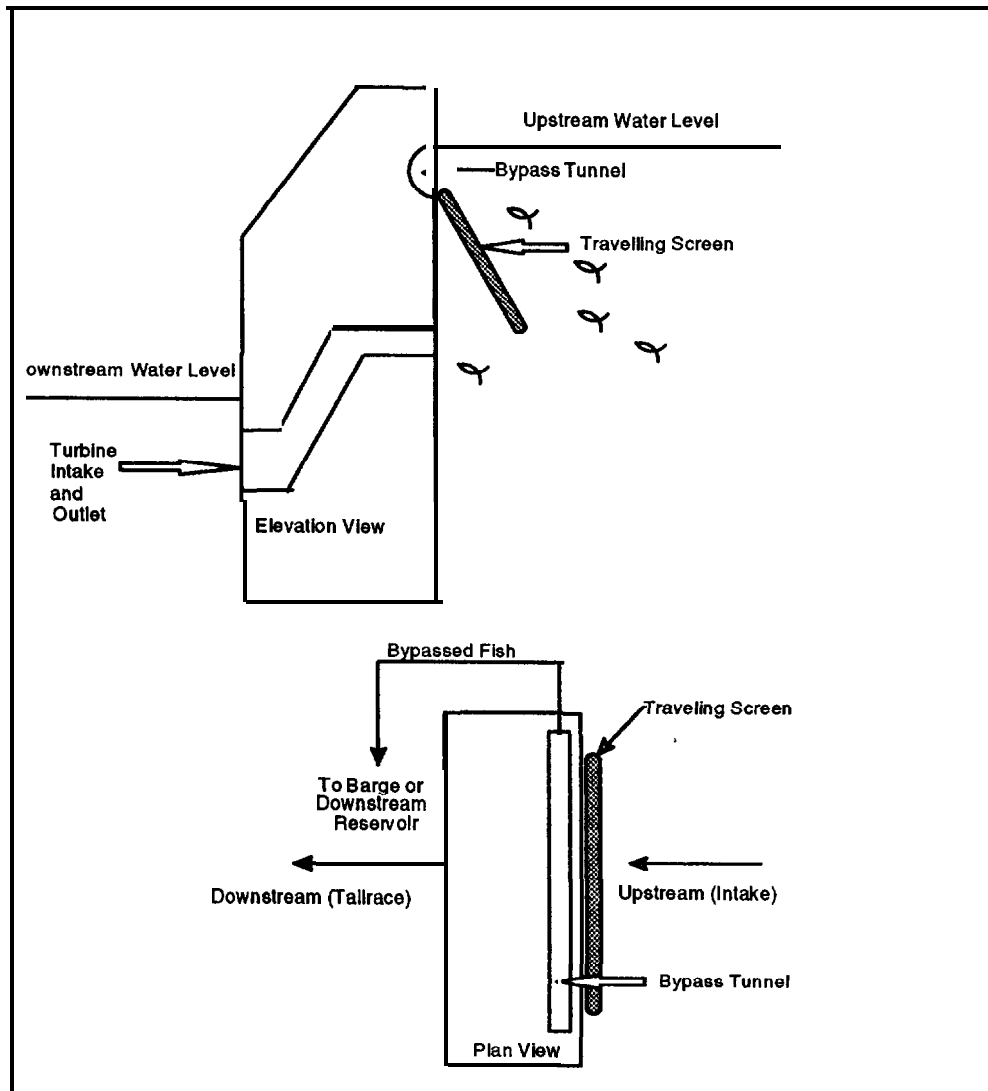
Figure 1.2 Smolt Bypass Schematic (not to scale)

to adulthood, as mentioned earlier. Several opportunities exist to regulate harvest by adjusting the timing, location, duration, and quotas of fisheries, and by controlling which stocks may be harvested and which are designated as catch and release. Many **subbasin** sport fisheries on salmon have been sharply curtailed or put on hold to allow for recovery of the stocks. Regulators also have increasingly restricted ocean and in-river harvests over the past decade. In 1992, salmon harvests in the Pacific Ocean were reduced dramatically, because of the low run sizes of salmon predicted for 1992.

Unfortunately, options for regulating harvest often are poorly integrated with passage, habitat, and hatchery options. Many argue that the poor integration results in large part from the highly fragmented administration of harvest management across the Basin.

<u>Habitat</u> <u>Improvement</u>: Mitigation for habitat problems in the subbasins includes barrier removal, stream habitat improvement, and screening of irrigation intakes. In some subbasins, a substantial amount of potential spawning ground remains unused because man-made or natural barriers block the path of returning spawners. Actions to allow upstream passage may involve either removal of the physical barrier (e.g., removal of a small dam) or construction of a bypass or ladder over the barrier (e.g., a fish ladder up a natural falls).

A large variety of actions fall in the category of stream habitat improvement, such as replenishing stream beds with spawning gravel, placing logs in streams to create pools, and replanting and protecting riparian vegetation. Recent legislative attempts to set minimum instream flows for fish during spawning and migration periods also could be categorized as habitat improvement.

The screening of irrigation water intakes attempts to prevent migrating juveniles from being routed into irrigation channels and stranded in irrigated fields. Because of the large toll that unscreened intakes may take on juveniles and the relatively straightforward nature of screening, agencies in the region currently are pushing to screen the worst intakes.

<u>Hatchery Management</u>: Although hatchery programs were originally conceived to be part of the solution to dwindling fish runs, there is concern that they may be part of the problem as

well, as we pointed out earlier. Recently-proposed hatchery programs take much greater account of the problems that potentially arise when hatchery fish are mixed with natural or wild fish. The Integrated System Plan (Columbia Basin Fish and Wildlife Authority, 1991b) discusses at length the issues, technology, and risks associated with hatchery supplementation programs (see also Meffe, 1992). In general, if hatchery input is used to supplement a natural population, implying that hatchery and natural fish will interbreed, then the hatchery fish should be as close to the natural fish as possible in their behavior, physiology, and genetics. This involves taking great care in broodstock selection and in rearing, acclimation, and release conditions. For most hatchery programs, a major efforts centers on tackling the problem of disease in hatchery populations to protect both the hatchery fish and the natural fish they may come in contact with. Moreover, since the goal of many hatchery programs is to provide harvest, it is important to develop fish marking schemes that allow stock-selective fisheries.

RESOURCES FOR THE FUTURE'S RESEARCH PROGRAM

In view of the complexity of the planning problem in regard to the fish mitigation problem, and BPA's responsibility for funding a major part of the effort,[7] BPA officials approached RFF in early 1984 requesting that RFF assist BPA in developing a research program in support of the mitigation effort. Of special relevance to the proposed research efforts are the requirements of the Northwest Power Act that damage to fish be mitigated while assuring a "safe, reliable, economic supply. . ." of electricity, that the region follow a system-wide approach, and that the measures undertaken be cost-effective.

Subsequently RFF proposed the outline of a research program to BPA. The program proposed by RFF was intended to be completed in three phases. Phase I, jointly sponsored by the BPA and RFF, was designed to identify economic and related research issues to be pursued in

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[7]In the 1980s, the region spent about $1 billion to rebuild Columbia River salmon runs and wildlife affected by federal hydroelectric facilities. Estimates of the costs of mitigation and recovery efforts for fish and wildlife in the next decade range from $1.5 billion to $3 billion. (BPA, 1991; Foster, 1992)

later stages of the research program. Allen Kneese delivered a document reporting on Phase I to BPA in mid-1984. The Phase II research was aimed at providing a comprehensive design of the research program -- including development of needed analytical methods, identification of data needs and potential sources, and a plan for the program's execution. We provided this to BPA in 1988 (Kneese, et al., 1988). We are conducting the bulk of the actual research in Phase III, although the Phase II planning effort involved considerable research in its own right.

The primary objective in the Phase III analysis is to provide a basis for examining the tradeoffs among alternative management strategies with regard to cost, numerical objectives for subbasin harvest, spawning escapement, and runsize, and non-numerical objectives such as genetic integrity. We have adopted a cost-effectiveness framework for this purpose (see Chapter 2).

Although we discuss the scope of the analysis, methods, and data sources in subsequent chapters and appendices, it is useful to understand at the outset what our analysis addresses and what it omits. Important points to note are:

1) We have restricted our analysis to chinook salmon and steelhead in subbasins above Bonneville dam. We include only those stocks with identifiable and documented proposed mitigation and recovery proposals and terminal harvest and spawning escapement objectives. In total, we evaluate actions for 79 hatchery and natural stocks. Table 5.1 provides a complete list of the included stocks and the spawning escapement and terminal harvest objectives for each stock.

2) We draw nearly all cost and biological information for subbasin propagation and passage actions from existing sources; that is, we did not conduct any new empirical field work. The only exception to our reliance on existing published data is that we updated some mid-Columbia hatchery cost information based on interviews with hatchery managers. We include only those subbasin propagation actions proposed in the CBFWA subbasin plans. Furthermore, we analyze only those proposed actions that have quantified costs and

associated   biological   effects.

3)   We do not assess management actions that change ocean or in-river harvest rates, although we do evaluate different terminal harvest rates.

4)   We evaluate only direct financial costs and opportunity costs of lost hydropower generation to Bonneville, and do not consider the possible economic costs and benefits to navigation, recreation, flood control, irrigated agriculture, dryland agriculture, or commercial and sport harvest.

5)   Our analysis adopts a deterministic framework, except for the variability introduced by different water years.

6)   Our analysis takes a comparative statics approach. We try to identify the lowest-cost means of meeting the specified objectives by some indeterminate future date. Thus, we do not investigate alternative rebuilding schedules or the implications of alternative sequences of actions.

7)   We adopt a system-wide perspective; that is, we investigate management options for downstream passage, subbasin propagation, and terminal harvest across all stocks simultaneously. For example, we do not fix conditions in the subbasin and look for the most cost-effective passage action. Our approach thus attempts to find the system-wide least-cost set of passage, propagation, and terminal harvest actions that will meet the specified objectives for each stock.

SUMMARYANDPLANOFREPORT

Many populations of Columbia Basin salmon are at very low levels. Direct and indirect mortality and habitat losses resulting from damming the river, harvest, habitat degradation due to a variety of human activities, and hatchery practices have all contributed to the declines of the fish

runs. Although many mitigation actions have been implemented during the 1980's, the situation remains critical for a number of stocks, especially the chinook and sockeye runs in the Snake River basin. Many more actions to benefit the fish have been proposed for the entire Columbia Basin, mostly involving mainstem passage enhancement, subbasin habitat enhancement, and hatchery programs. Examining the trade-offs among expenditures, objectives, and constraints of alternative recovery strategies, to provide decision-makers with information on how these aspects of the problem affect one another, is the overall goal of our work described in this document.

In the remaining chapters, we describe the data, models, analyses, and results associated with our system-wide cost-effectiveness analysis of mitigation and recovery alternatives in the Columbia Basin. In the next chapter, we provide the conceptual underpinnings of the cost-effectiveness approach that we have adopted. Chapter 3 presents an overview of the models that we use in our analysis and describes their interconnections. Chapter 4 discusses the data that we use, as well as the objectives that we include in our cost-effectiveness analysis. We furnish results in Chapter 5. The appendices at the end of this report are for those readers who are interested in the details of the models and the data. We also provide a glossary at the end of the report to clarify some of the important concepts of our discussion.

CHAPTER 2
COST-EFFECTIVENESS AND SYSTEM COMPLEXITY

INTRODUCTION

The main questions we address in the work presented in this report are (1) what actions should the region implement to achieve a set of goals for the fish at least cost, and (2) how do changing goals or constraints affect the least-cost choice of actions? These questions are easy to pose yet extremely difficult to answer. For a complex system like the Columbia Basin, the design and exercise of a basin-wide, multiple-stock analysis that can provide information to address these questions present a daunting task. It is difficult to evaluate each possible management option for each stock while keeping track of **the tradeoffs with** other possible management options and stocks. On the other hand, if we focus on individual stocks and subbasins and proceed with an analysis on a stock-by-stock basis in order to make our analysis more tractable, we may fail to see the possible positive and negative interactions among stocks. In this situation, we may unknowingly choose a set of actions that benefit some stocks but have deleterious economic and/or biological effects in the aggregate.

We have chosen a basin-wide approach for our analysis, since we believe that decision makers in the Pacific Northwest ultimately must make decisions about management options for stocks throughout the basin. However, to work at the basin-wide level and to provide a reproducible and justifiable account of the tradeoffs among options, we need a sound conceptual and analytical framework. The framework on which we base our work is cost-effectiveness analysis. We use the method to examine the tradeoffs between different courses of action with respect to cost, biological effectiveness, and other variables of interest, in a system context. While this approach handles the large, interconnected system well, it also can be used fruitfully at much smaller spatial scales and for less-complex systems.

In this chapter, we briefly discuss the concept of cost-effectiveness analysis and the complexity of such an analysis in the Columbia basin. We start with a brief overview of the technique. We next provide a simple didactic example of a cost-effectiveness analysis. We then

discuss the complexity of the Columbia River system and its management and present a classification of management actions and strategies which we use to find basin-wide, least-cost solutions to the problem of mitigation and recovery planning for Columbia basin salmon and steelhead.

OVERVIEW OF COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is a useful tool for exploring tradeoffs among any number of alternative strategies with respect to costs and measures of effectiveness (e.g., number of adult fish that escape to a subbasin). In brief, with the approach we attempt to find the least-cost way to achieve some desired, pre-set level of effectiveness. Moreover, we can vary the desired level of effectiveness over a range of values, and for each level find the least-cost alternative. [1]

If we plot the costs and effects of alternative management options on a graph and identify the least-cost strategies for a number of desired levels of effectiveness, we can trace the "frontier" of cost-effective strategies. This frontier graphically highlights the potential cost-savings associated with choosing cost-effective strategies, because points on the frontier provide equal or higher levels of effectiveness at lower cost than points not on the frontier. The frontier also shows that higher levels of effectiveness mean not only higher costs, but also generally smaller increments in effectiveness for a given increase in cost (i.e., increasing marginal costs).[2]

It is important to note that cost-effectiveness analysis differs significantly from cost-benefit analysis. While cost-benefit analysis attempts to evaluate whether the benefits of a particular alternative exceed the costs, cost-effectiveness analysis attempts to identify the least-cost alternative for a given objective. Cost-effectiveness thus says nothing directly about the desirability of attaining a given objective. Although this may limit the usefulness of cost-effectiveness analysis in some venues, we believe that in mitigation and recovery planning for

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[1]See Spofford (1989) for more details on applications of cost-effectiveness analysis.
[2]In theory, the marginal costs of alternatives on the cost-effective frontier will increase as the level of effectiveness increases. However, this does not necessarily hold true in real-world applications, as our results in Chapter 5 display.

salmon populations in the Columbia basin it does not. The clear separation of biological

objectives and economic costs furnished by the cost-effectiveness framework provides both a

simpler and a more relevant approach than does a cost-benefit framework, which would require

estimating the monetary value of the benefits derived from preservation or enhancement of the

salmon populations. Furthermore, the language of the Northwest Power Act clearly promotes the

use of cost-effectiveness analysis.

COST-EFFECTIVENESS EXAMPLE

Table 2.1 and Figure 2.1 help illustrate a simple example of a cost-effectiveness analysis.

Table 2.1 presents fifteen hypothetical strategies which increase adult run sizes, with

accompanying costs and biological effects (for purposes of the example, assume that each strategy

contributes a certain number of adult fish). We plot these points in Figure 2.1, with costs in the y

dimension and number of adult fish in the x dimension. We then trace the cost-effective frontier.

Each point on the frontier represents the lowest cost strategy which provides the corresponding

number of adult fish. Strategies not on the frontier are economically and/or biologically inferior,

because one can attain at least as many adults with another, lower-cost strategy (compare

strategies 2 and 7), or a higher number of adults with another strategy, at the same cost (compare

strategies 9 and 4).

The results of the hypothetical analysis depicted in Figure 2.1 portray costs and effects for

the entire set of fifteen strategies. But other attributes besides cost and effectiveness may merit

consideration in the evaluation of different strategies (e.g., public support for a strategy and the

numerical strength of the targeted stock). We incorporate these additional attributes by allowing

them to constrain the types of strategies that we consider or the objectives we seek.

To illustrate how this works, consider the example displayed in Figure 2.2. This figure

shows two cost-effectiveness frontiers: the original frontier from Figure 2.1 (Frontier I) and a new

frontier (Frontier II, indicated by arrows, using only the bold-face numbers) beside it. We

produce the new frontier by omitting from the cost-effectiveness analysis those strategies that rely

TABLE 2.1
Cost and Effectiveness of Hypothetical Strategies to Increase Run Size

Management Action Code	Management Action Description	Additional Adults	Annualized Cost (thousand $)
A	Improve Existing Habitat I	1,700	$50
B	Add New Habitat I	5,000	$400
C	Improve Existing Habitat II	6,250	$1,100
D	Add Hatchery	3,000	$1,500

Management Strategy	Action(s) Included	Additional Adults	Annualized Cost (thousand $)
1	A only	1,700	$50
2	B only	5,000	$400
3	C only	6,250	$1,100
4	D only	3,000	$1,500
5	A & B	6,700	$450
6	A & C	7,950	$1,150
7	A & D	4,700	$1,550
8	B & D	8,000	$1,900
9	B & C	11,250	$1,500
10	C & D	9,250	$2,600
11	A & B & C	12,950	$1,550
12	B & C & D	14,250	$3,000
13	A & B & D	9,700	$1,950
14	A & C & D	10,950	$2,650
15	A & B & C & D	15,950	$3,050

Figure 2.1. C/E **Example**

Figure 2.2. C/E Example Without New Habitat
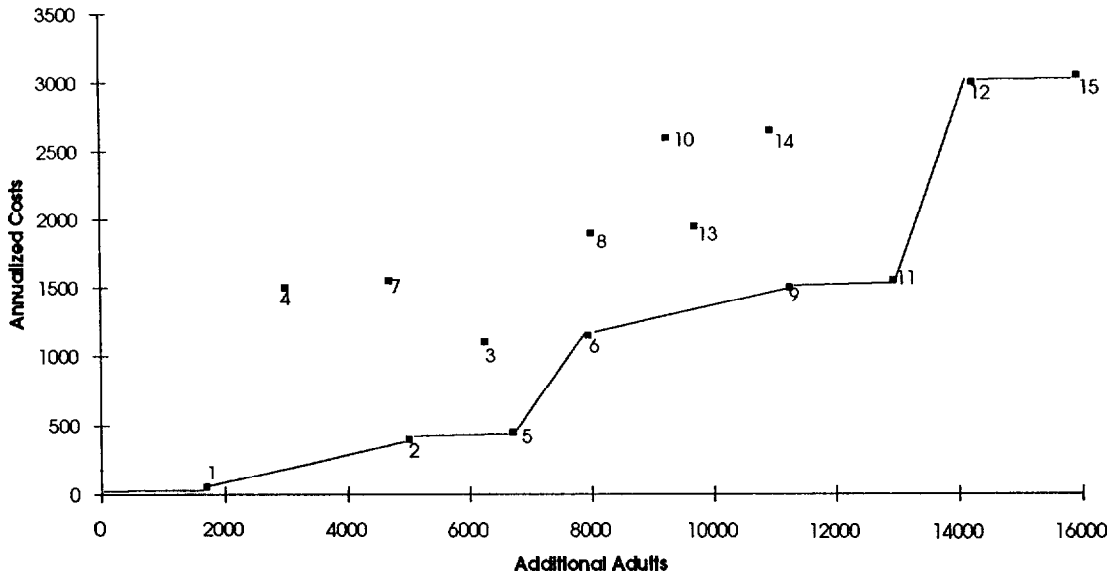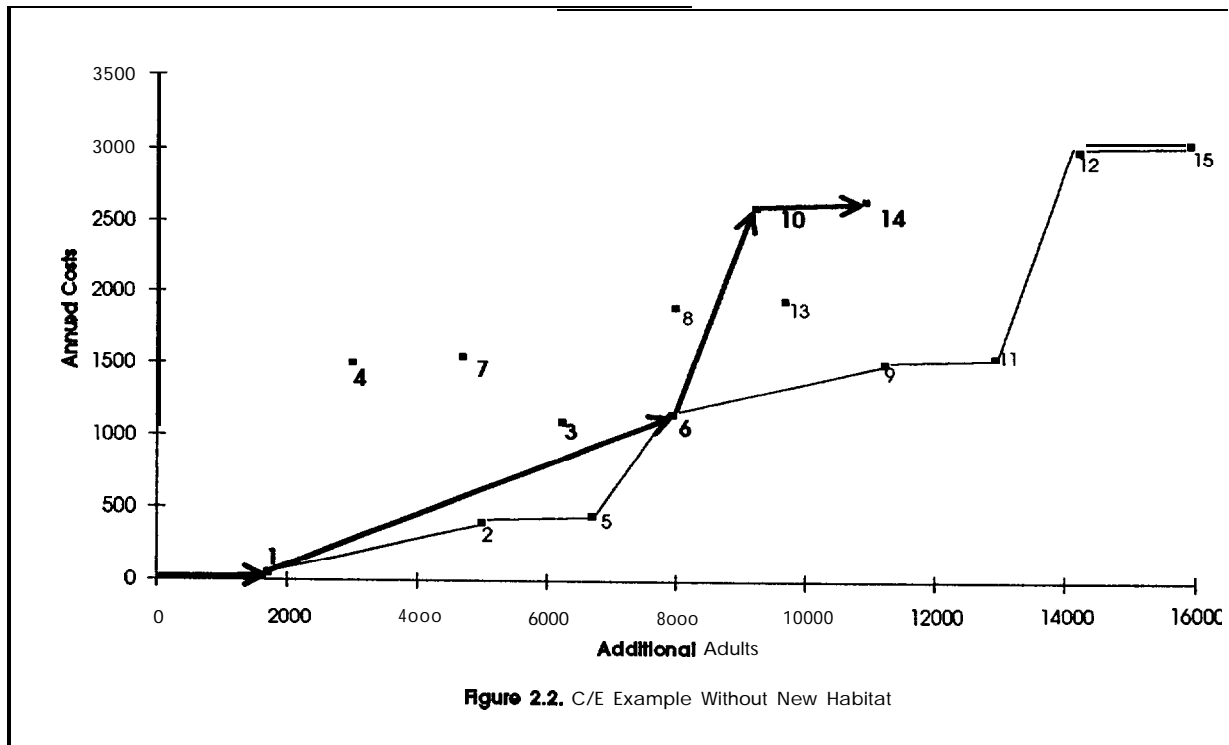
on new habitat (perhaps due to concern about resident fish); 7 strategies remain. We then compare the new cost-effectiveness frontier for the 7 strategies to the frontier for the entire set of 15 strategies. Such a comparison can tell us the effect that rely on existing habitat has on the composition and choice of cost-effective strategies. This simple extension of the basic analysis thus allows us to explore the implications of emphasizing attributes other than cost and effectiveness.

The immediate objective of the cost-effectiveness analysis is to define the least-cost strategy that will meet a set of stock-specific objectives for subbasin harvest and spawning escapement. The strategy will use a combination of passage actions (which affect all stocks simultaneously), subbasin-specific propagation actions, (which affect all stocks spawning in the subbasin), and harvest rates (which affect each stock individually). The larger goal of the analysis is to explore tradeoffs among expenditures, biological effectiveness, and other attributes to provide decision-makers with information on how the multiple dimensions of recovery planning affect one another.

SYSTEM COMPLEXITY

In the work discussed in this and subsequent chapters, we extend the methods demonstrated in the above example to the portion of the Columbia basin bounded by Bonneville Dam, Hells Canyon Dam, Chief Joseph Dam, and Dworshak Dam. (See Figure 1.1) Although our system-wide analysis follows the simple logic of Figures 2.1 and 2.2, the large number of stocks, propagation strategies, and passage strategies complicates the picture. This section addresses the complexity of the decision problem which results from our efforts to take a basin-wide perspective on the enormous number of combinations of recovery actions that the region must evaluate.

Species and Stocks

The area above Bonneville Dam currently boasts a number of species of anadromous fish: steelhead, sockeye salmon, coho salmon, and several runs (spring, summer and fall) of chinook salmon. Of these we have excluded sockeye and coho from our analysis, due to the lack of both biological data and stock-specific objectives for most sockeye and coho populations. We also have excluded Hanford Reach chinook, mid-Columbia steelhead, and several other stocks because of data limitations and/or an absence of proposed mitigation actions. Finally, we have excluded all stocks in the Yakima subbasin, since this basin already has major mitigation projects underway.

The subbasin plans developed by the Columbia Basin Fish and Wildlife Authority (CBFWA, 1990) that provide the foundation of our work divide the species into stocks, based upon the subbasin where they spawn and whether they are of hatchery or natural origin. We make an additional division of hatchery-origin fish into "pure" hatchery and supplementation stocks (Chapter 4 offers more information on stock definitions). In total, we analyze management objectives and management actions for 79 stocks.

Mitigation Actions and Strategies

In addition to the large number of stocks, three other factors complicate the analysis. First, as noted earlier, passage actions can affect more than one stock at a time. Actions specific to a particular dam can affect every stock above that dam, and flow actions can influence the survival of all smolts migrating during the period when the flow action is in operation. Even within subbasins, propagation actions often affect every stock which spawns in the subbasin (e.g., removal of a barrier on a tributary stream). Thus, one cannot hope to find a basin-wide combination of passage and propagation actions to meet the stock-specific objectives at least cost without taking account of the possible multiple effects of passage and propagation actions,

Second, the effects of some actions are not entirely independent of each other when viewed in a life cycle context. For example, an action which increases the downstream survival of a stock's smolts by 100 percent may lead to a less than 100 percent increase in that stock's

abundance if the population already lies near the subbasin's carrying capacity. This possibility necessitates a life-cycle approach which combines passage, propagation, and harvest.

Third, the sheer number of possible combinations of the proposed recovery actions is very large. A simple example may illuminate this problem. Consider first a single subbasin, "'A", having a single stock, with 3 propagation management actions, denoted A1, A2, and A3. e define underlined terms from this section in Table 2.2). We can define these propagation actions into eight propagation strategies: AO, or no action, Al only, A2 only, A3 only, AlA2, A1A3, A2A3, and A1A2A3. Next, analogous to the methods used in subbasin planning, let us assume that managers can vary the terminal harvest rates for the stock, and that they can employ any of three terminal harvest rates, AT1, AT2, or AT3. Even if the whole system consists of only this one subbasin, we still need to consider 24 propagation/terminal harvest combinations to be considered (8 propagation strategies * 3 terminal harvest rates). If one then adds 4 passage strategies (PO, or no action, P1 only, P2 only, and P1P2, derived from 2 passage actions, P1 and P2), the number of propagation/terminal harvest/passage alternatives for the subbasin increases to 96 (24 propagation strategy/terminal harvest rate combinations * 4 passage strategies). While this number seems high, considering the small number of propagation strategies, terminal harvest rates, and passage strategies, it is still manageable. In our cost-effectiveness modeling, we can easily evaluate this number of alternatives with the deterministic simulation model, described in more detail in Appendix A.

What happens when we add another subbasin, "B", to the example? Assume that subbasin B also has three propagation actions, B1, B2, and B3, resulting in 8 propagation strategies, and three possible terminal harvest rates, BT1, BT2, and BT3. Obviously, subbasin B also will have 24 propagation strategy/terminal harvest rate combinations. If we add the four possible passage strategies, subbasin B also will have 96 propagation strategy/terminal harvest rate/passage strategy alternatives. An analysis that investigates the two subbasins *in isolation* from each other would require 192 runs of a simulation model, since both subbasin A and subbasin B have has 96 alternatives. The deterministic simulation model can accommodate this number of simulations.

TABLE 2.2
Definitions of Terms Used to Specify Mitigation Options

Term	Definition
Management Action	Smallest single management option that will have a unique effect on a biological parameter; e.g., add screens at a run-of river dam, or add rearing capacity at a hatchery.
Passage Strategy	Combination of passage actions; will affect all stocks in the system simultaneously; can only use one passage strategy for the entire system.
Propagation Strategy	Combination of propagation actions; will affect all stocks in a given subbasin simultaneously. Exactly one propagation strategy per subbasin.
Propagation/Passage/Terminal Harvest/Alternative	Combination of a system-wide passage strategy, subbasin-specific propagation strategy, and stock-specific terminal harvest rate, for a single stock. The alternative defines all the information necessary to calculate the adults produced for a given stock. Generated by the deterministic simulation model.
System-Wide Strategy	Combination of propagation/terminal harvest/passage alternatives for all stocks in the model. All stocks use the same passage strategy and all stocks within a given subbasin use the same propagation strategy, although different stocks in the same subbasin may have different terminal harvest rates.
System-Wide Least-Cost Strategy	The system-wide strategy which meets a set of biological objectives at the lowest possible cost of subbasin-specific propagation strategies and one passage strategy. Generated by the linear programming model, using alternatives generated by the deterministic simulation model.

However, if decision makers want a basin-wide analysis of subbasin A, subbasin B, and passage options, the difficulty of the evaluation increases dramatically. The number of possible system-wide strategies, defined here as all possible propagation strategy/terminal harvest rate/passage strategy alternatives for subbasin A **and** all possible propagation strategy/terminal harvest rate/passage strategy alternatives for subbasin B, increases to 2,304 system-wide strategies -- (24 propagation/terminal harvest combinations for subbasin A) * (24 propagation/terminal harvest combinations for subbasin B) * (4 passage strategies). Although the deterministic simulation model can easily simulate this number of system-wide strategies, identification of the least-cost system-wide strategy that meets the objectives would require analyzing 2,304 sets of results. One cannot say what the system-wide costs and biological results would be simply from an examination of the two sets of 96 alternatives in isolation from each other. In the Columbia basin, the number of possible sets of results to sort through becomes astronomically large.[3]

The analysis of the results and identification of the least-cost system-wide strategy for recovery planning in the Columbia basin thus requires some sort of screening mechanism to sort through the billions of different strategies. We discuss the linear programming model which we developed to perform this screening function in the next chapter and Appendix B.

CONCLUSIONS

In order to provide useful information to inform decisions about which actions the Pacific Northwest should implement to achieve a set of goals for the fish at least-cost, we have adopted a cost-effectiveness framework. The framework allows us to uncover the least-cost set of actions, as well as investigate how changing goals and constraints affect the least-cost choice. The need to integrate passage, propagation, and harvest options to provide a basin-wide least-cost strategy complicates the cost-effectiveness analysis, because it forces us to analyze an astronomical

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[3]We estimate that we need to assess $7 * 10^{47}$ possible combinations of passage, propagation, and harvest. Although we can take shortcuts to eliminate many of these combinations, we still face billions of system-wide strategies to analyze.

number of possible combinations of management options. However, while the large number of combinations makes the analysis difficult, it does not make the problem intractable.

We have developed a linear programming model to screen the combinations of management actions. The model uses output from a deterministic simulation model,[4] and systematically searches for the combination of alternatives which produces a system-wide least-cost strategy to meet a set of terminal harvest, spawning escapement, run size, or other biological objectives at least cost, without violating any constraints we impose, such as maintenance of genetic integrity. We discuss our modeling approach in the next chapter.

[4]The simulation model estimates the number of adults produced by each propagation strategy/terminal harvest rate/passage strategy alternative for each subbasin and stock.

CHAPTER 3
MODELING OVERVIEW

INTRODUCTION

The basin-wide cost-effectiveness analysis discussed in Chapter 2 relies on the application of a suite of computer models, which analysts in the Pacific Northwest and at Resources for the Future have developed over the last ten years. Each of the models that we use contributes a piece of information to our analysis. Since none of the models individually can provide the full range of information necessary for the cost-effectiveness analysis, we link them together. The linked models collectively constitute the cost-effectiveness modeling process.

This chapter describes each model's history of development, general logic, necessary inputs, outputs, and role in the cost-effectiveness analysis. We start with the model which simulates physical characteristics and economic costs of the operation of the Columbia Basin hydropower system (System Analysis Model). We then move to the simulation of the downstream passage of smolts from upriver sites to the estuary below Bonneville dam (Columbia River Salmon Passage Model). We next focus on the model which simulates the entire life cycle of salmonids in the Basin (Deterministic Life Cycle Model). We finish the model overview with the System-Wide Optimization Model, which uses inputs from the other models to identify system-wide cost-effective strategies for Columbia Basin fisheries management. We conclude the chapter with a brief recounting of the links between the models. The reader may find it useful throughout this chapter to refer to Figure 3.1, which depicts the relationships among the models that we discuss.

SYSTEM ANALYSIS MODEL

The System Analysis Model (SAM) performs a simulation of the region's power system to meet the demand for capacity and energy within the region. The Northwest Power Planning Act that was passed in 1980 highlighted the need for a tool which could model the operation of the region's power system, both for shorter-term operational guidance and for longer-term planning
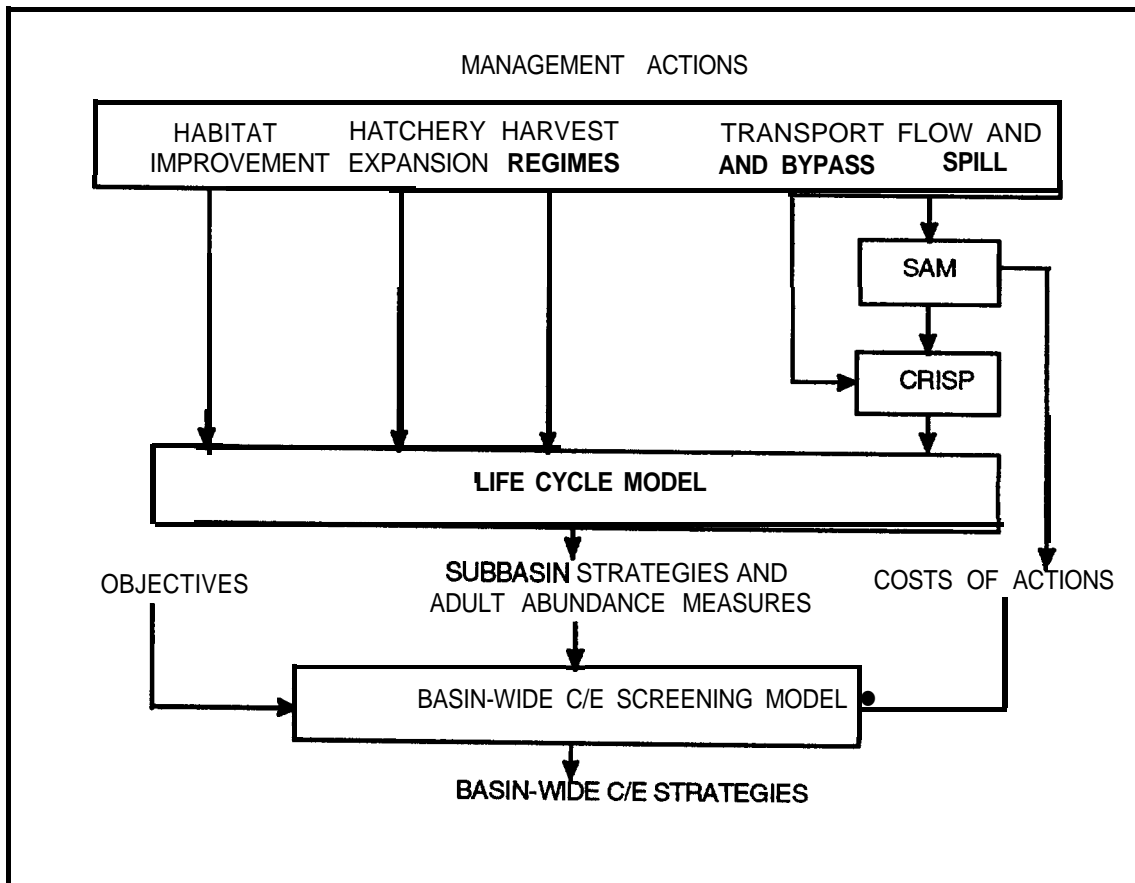
Figure 3.1. Relationships Among Models Used In Cost-Effectiveness Analysis

for the acquisition of power generating resources. Begun in 198 1, SAM has evolved into a complex collection of sub model components, with the capability to model the operation of the hydro and thermal power resources needed to meet demand season-by-season, month-by-month, or hour-by-hour. For a complete description see the SAM documentation (Pacific Northwest Utilities Conference Committee, 1983).

The model works in a Monte Carlo framework and depicts variability in both energy supply (due primarily to changing water condition) and demand. Although SAM assumes a single-owner system, the model does not optimize the operation of the power system. Rather, it simulates the short-term, least-cost operation for a given mix of available generating resources. Given a set of natural water conditions, a mix of available generating resources, and load forecasts, SAM can provide estimates of the revenue requirements necessary to cover the costs of operating resources to meet the load. Generally, a run of the simulation model covers a twenty-year planning horizon and forty or fifty games.[1]

The most salient outputs of SAM for the cost-effectiveness analysis are the monthly regulated flows (from companion hydro-regulator models) and associated revenue requirements. Load constraints and the capability of resources to meet these loads, natural water conditions, and non-power constraints such as minimum flows and spill for fish determine the regulated flows. The revenue requirements depend in large part on these regulated flows, because generally as hydrosystem operators alter their flow regulation for reasons other than producing power (e.g., to provide flows for fish), the costs of operating the power system increase. The cost increases occur both because the region may need to operate higher-cost generating resources and because the value and/or quantity of hydropower sold may decrease. SAM can report revenue requirements for each Monte Carlo game or the average revenue requirement over all games, for

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[1]The planning horizon refers to the span of system operation which a simulation exercise covers (e.g., twenty operating or power years from 1992 to 2011). A game refers to each simulation of the planning horizon in the Monte Carlo process (e.g., forty games means forty simulations of the twenty year planning horizon). The sequence of natural water conditions (water years) provides the major source of variability in SAM's simulation of hydropower generation.

each year in the planning horizon.

As Figure 3.1 displays, the revenue requirement and regulated flows outputs from SAM serve as inputs to other parts of **the** cost-effectiveness analysis. More specifically, **the difference** in revenue requirements between operating the power system under a particular flow scenario (e.g., the Council's Phase II Amendment) and a base case (e.g., current operations) becomes the hydropower-related cost of that scenario. We express this difference as the average difference over a **50-game,** 1 power year simulation. Thus, the hydropower-related costs that we report from a flow scenario do not represent the average overall revenue requirements for operating under that scenario, but rather the marginal increase (or decrease) in average revenue requirements. The regulated flows passed from SAM to the downstream passage model described next are monthly regulated flows for each water year (game) at each run-of-river project.

COLUMBIA RIVER SALMON PASSAGE MODEL

The Columbia River Salmon Passage Model (CRiSP) simulates the downstream migration of salmon and steelhead smolts from their initial entry into the mainstem Columbia and Snake rivers to a point just below Bonneville dam, the lowest mainstem dam on the Columbia River. The version of CRiSP (CRiSP.0) that we use in our cost-effectiveness analysis accounts for smolt mortality due to turbine, bypass, spillway, and sluiceway passage at each of 13 mainstem dams, and mortality associated with passage through the reservoirs behind each dam (the user can supply several different flow/travel time/mortality relationships for reservoir passage). CRiSP also models the collection and transportation of smolts. The CRiSP.0 documentation by Hinrichsen et *al.* (1991) provides extensive details on the model.

The Center for Quantitative Science at the University of Washington developed CRiSP.0 for the Bonneville Power Administration in 1990- 199 1, but the origins of the model lie in the FISHPASS salmon passage model developed by the U.S. Army Corps of Engineers in the mid-1980s (Swartzman et *al.,* 1990; Tanovan, 1985). CRiSP.0 is a user-friendly, graphical version of

FISHPASS, with a few minor coding modifications, and a different platform (CRiSP.0 currently operates on a SUN workstation in a UNIX environment, whereas FISHPASS operates on a mainframe or mini computer). CRiSP.0 introduces smolts (spring, summer, and fall chinook, sockeye, and steelhead) into the mainstem at user-specified points on a daily basis, and tracks the survival of smolts through each downstream reservoir and project. Mortality in reservoirs depends on daily average flows (computed from the SAM inputs), reservoir length, and (indirectly) level of transportation, while mortality at dams accrues hourly, and depends primarily on the efficacy of bypass structures and spill levels. CRiSP.0 tracks fish migration from April through September for each operating year in the planning horizon and for each game (water year).

In order to simulate the effects of the management actions in our cost-effectiveness analysis, we altered one or more of the six CRiSP.0 input files that contain parameters which represent the effects of the actions. For example, to model the effects on survival of reducing predator populations by twenty percent, as called for in the NPPC's Phase II Amendment (NPPC, 1991a: 27), we reduced the predator multiplier parameter for all species at all projects in the species input file. We also modified the input files to test different assumptions about the efficacy of passage actions and the biological processes at work. For example, we do not know with certainty the flow-mortality relationship for each stock, so we tried two different forms of survival relationships (constant mortality per day and a broken stick model). We ran CRiSP.0 under the two relationships and analyzed the difference in survival. (Table 3.1 displays the relevant input file for each passage action that we modeled, while Chapter 4 discusses the passage management actions in more detail.)

The output of each CPiSP.0 run can provide estimates of survival proportions for fish, separated into groups by stock, species, pool of origin, and/or hatchery verses natural. The model can supply overall system survival for each grouping, as well as pool and dam survivals. We generated only system survivals for each stock of interest, since our primary concern lies with the contribution that each passage strategy makes to fish survival below Bonneville. In each CPiSP

TABLE 3.1
CFWP.0 Input Files

Input File	Description	Modeled Passage Actions Affected by Input File
SAM	flow volumes at each of 13 projects by month, for each water year	flow scenarios
spill	hours, day, amount, and location of fish spill	none
modulate	ratio of daily average flow to monthly average flow for each month, at each of three control points	none
dam	powerhouse, sluiceway, and transportation operation schedules at each project	level of transportation
species	control parameters for each species at each project and pool, flow-travel time survival relationship (including effects of lower reservoir elevation, degree of predator control	predator control, transportation survival, fish guidance efficiencies
stock	timing, location, and number of fish entering mainstem Snake and Columbia, by stock	timing of fish entering mainstem

run we obtained fifty survival values for each stock, corresponding to the 50 games or water years. We use the mean survival over the fifty games for each stock as input to the deterministic life cycle simulation model.

DETERMINISTIC LIFE CYCLE MODEL

The Deterministic Life Cycle Model (DLCM) developed at RFF simulates the life cycle of anadromous salmon and steelhead. We designed the DLCM so that it not only would mimic the basic factors regulating populations of Pacific salmonids, but also so that it would run relatively fast and require relatively simple set-up procedures. Speed and simplicity are important because the DLCM must simulate the biological effects of nearly 100,000 passage/propagation/terminal harvest alternatives.

We can conceptualize the DLCM as a series of linked compartments corresponding to stages within the life cycle. For any one simulated stock, each life stage requires at least one input from the previous stage and provides at least one output to the subsequent stage; some stages also may have other outputs (e.g., harvest and hatchery broodstock take). The number of fish alive at each stage during any given year are the state variables of the model. Figure 3.2 provides a schematic representation of how the different life stages connect with one another. We furnish a more detailed description of the DLCM in Appendix A.

The DLCM resembles the System Planning Model (SPM) and other deterministic life-cycle models in basic structure, but it contains less detail in that it does not consider separate age classes. Data inputs to the model include parameters describing the number of eggs spawned per female each year, the proportion of fish surviving from one stage to the next, harvest and brood-stock removals, and the proportion of fish surviving from the migrant smolt stage to below **Bonneville dam (calculated in CRiSP). The values of all of these parameters depend on the** management strategy being simulated. After supplying the input parameter values, we run the DLCM over a planning horizon that will allow the state variables to equilibrate. Model outputs include the number of adults that return to each subbasin, fish caught in the subbasin (terminal)
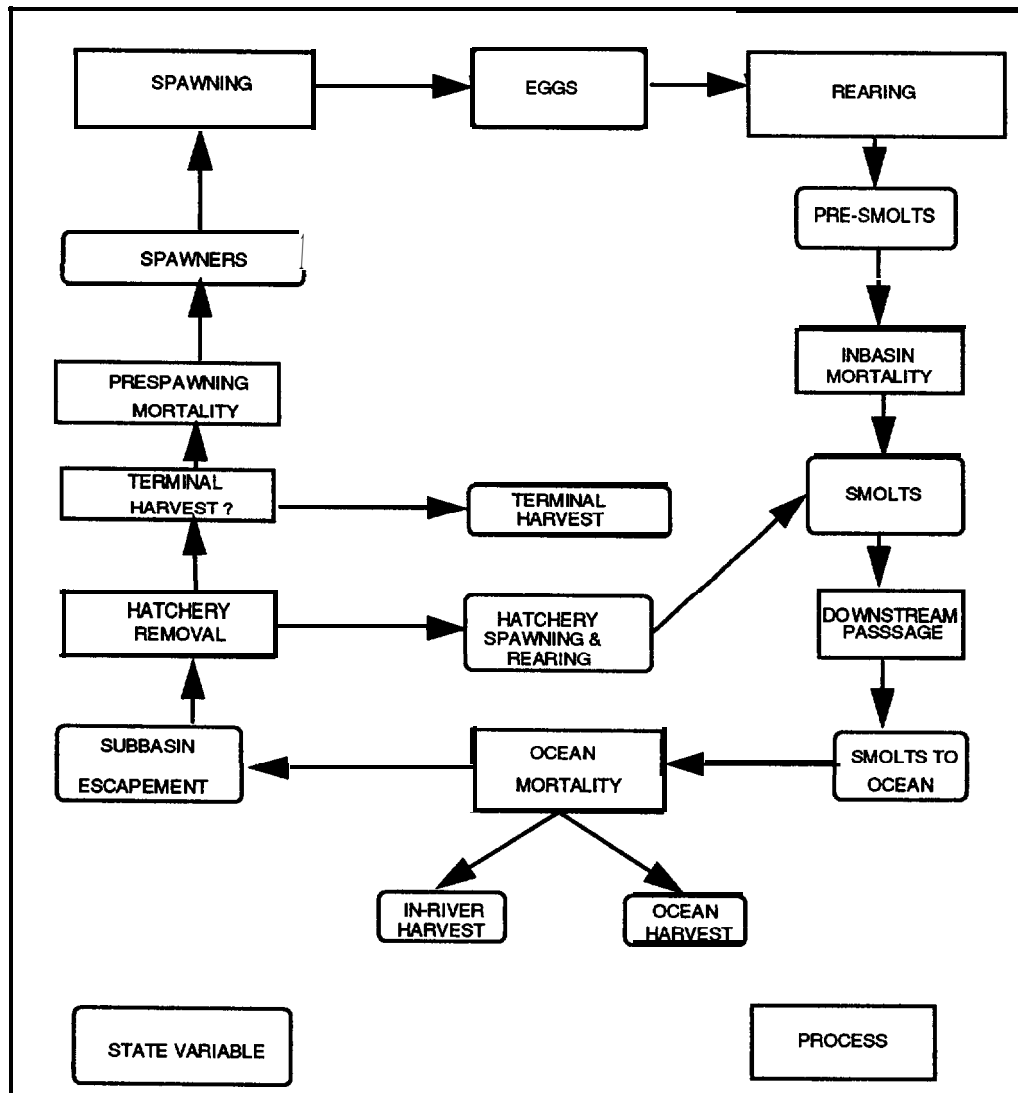
FIGURE 3.2 : SALMON LIFE CYCLE

harvest, and spawners, at equilibrium, for each stock. These outputs constitute the measures of effectiveness for each propagation/passage/terminal harvest alternative modeled, and furnish the biological inputs to the System-Wide Optimization Model.

SYSTEM-WIDE OPTIMIZATION MODEL

The system-wide optimization model processes cost data for propagation and passage actions, and biological outputs from the DLCM, in order to select the system-wide strategy which meets various objectives for each stock at lowest cost. As Chapter 2 points out, a very large number of possible propagation/passage/terminal harvest alternatives that meet the objectives may exist. Since we can not practically sort through the entire set of combinations of alternatives to find the least-cost system-wide strategy in a reasonable amount of time, we have developed a model that relies on linear programming techniques to find the least-cost solution in an efficient manner.

Appendix B describes the system-wide optimization in detail, but a few points merit mention here. First, although a single run of the optimization model identifies only a single least-cost, system-wide strategy (composed of propagation, passage, and terminal harvest alternatives for all stocks), the model can identify a set of least-cost, system-wide strategies for different levels of fish (a cost-effectiveness frontier) with multiple runs. Each run would entail a different set of objectives. For example, we can perform a series of model runs with the level of the numerical objective in each run set to some proportion of the numerical levels specified in the subbasin plans. In the first run, we may set the objective at 100 percent of the numbers specified in the subbasin plans, in the second run we may set the objective at 80 percent of the numbers specified in the subbasin plans, in the third run 110 percent of the subbasin plans levels, and so forth. Similarly, we can obtain the least-cost strategy for different kinds of objectives with multiple runs. For example, if we wish to identify the least-cost system-wide strategy which will furnish a particular number of fish and will not rely on hatchery production, we can eliminate alternatives which contain hatchery actions and use the optimization model to find the least-cost system-wide

strategy that remains. This provides an important feature, since it gives the optimization model the capability to look beyond simple tradeoffs between dollars spent and fish numbers.

Second, the system-wide optimization relies integrally on two other models described in this chapter. The System Analysis Model furnishes estimates of the marginal costs of each alternative flow or spill scenario. The Deterministic Life Cycle Model provides the biological effects for the entire set of propagation/terminal harvest/passage alternatives that the optimization model searches through. The set of feasible system-wide strategies (i.e., those system-wide strategies which meet the objectives for all stocks) will come from these alternatives.

Third, the optimization model relies on a database of cost estimates for each propagation, passage, and harvest action. We have not discussed the cost estimates in this chapter, since the estimates are not models themselves, but the reader should note that the optimization model requires an extensive cost data base. Chapter 4 describes the sources and assumptions behind the cost estimates.

Finally, we designed the system-wide optimization model for the explicit purpose of identifying least-cost, system-wide strategies from the set of alternatives supplied by the deterministic life cycle simulation model. As such, the optimization model currently does not present a user-friendly interface with easy-to-follow, click-and-run instructions (in contrast to CRiSP). The concepts and approach in the model reflect straightforward and well-established norms, but we would be doing a disservice to the reader if we gave the impression that the present version of the optimization model is simple to operate.

CONCLUSIONS

The models outlined in this chapter -- SAM, CRiSP.0, Deterministic Life-Cycle Model, and the System-Wide Cost-Effectiveness Optimization Model -- collectively form the base of our assessment of system-wide strategies for salmon and steelhead recovery planning in the Columbia basin. These models, together with databases containing information on the costs and survival benefits of alternative strategies, provide useful tools for exploring the cost-effectiveness of

alternative actions and tradeoffs in trying to reach different levels or kinds of objectives.

The models play important roles in their own right, but their real utility in cost-effectiveness analysis comes from linking them together. The System Analysis Model provides a means by which we can model the hydrological and economic aspects of alternative flow and spill scenarios. The hydrological outputs from SAM serve as inputs to the flow component of CRiSP.0, which generates the downstream passage survivals for each stock. We use these passage survivals in Deterministic Life Cycle Model, which simulates the life-cycle of salmonids from egg to spawning adult. The results from the deterministic model, together with cost data from SAM and other sources, constitute the inputs for the optimization model, which ultimately allows us to evaluate the cost-effectiveness of alternative strategies.

In Chapter 4, we provide more information on the costs and biological effects of proposed propagation and passage actions, data sources, and our classification of salmon and steelhead stocks. We also discuss the goals, objectives, and constraints that we place in the models. Readers interested in more details on the Deterministic Life Cycle Model and the optimization model should refer to Appendices A and B, respectively.

CHAPTER 4
DATA INPUTS, ASSUMPTIONS, AND OBJECTIVES

INTRODUCTION

The preceding three chapters have laid the groundwork for our system-wide cost-effectiveness analysis of passage and propagation actions to enhance salmon and steelhead populations in the Columbia basin. This chapter discusses data inputs, assumptions made to facilitate the analysis, and objectives included in the evaluation. We start with a discussion of the propagation strategies proposed in each subbasin. The section following this discussion describes the passage strategies evaluated in the analysis. We then briefly explain how we incorporated different terminal harvest rates. We follow these discussions of data inputs with a section that addresses some of the major assumptions used in the analysis. We then outline the goals and objectives included in the analysis. The final section presents a brief discussion of sensitivity testing. [1]

PROPAGATION STRATEGIES

Propagation actions can be categorized into four types: hatchery program initiation or expansion, habitat improvement, diversion screening, and barrier removal. The subbasin propagation actions that we analyzed largely come from the subbasin plans developed under the auspices of the Northwest Power Planning Council and the Columbia Basin Fish and Wildlife Authority (Columbia Basin Fish and Wildlife Authority, 1990). The plans delineate the subbasins and stocks of interest, and furnish most of the quantitative information on the costs and biological effects of propagation actions that we include in our analysis. However, we modified the information and analysis presented in the subbasin plans in several ways.

First, we modeled a stock only if it had both numerical objectives associated with it and at least one specific, quantifiable propagation action (with identifiable costs and biological effects) targeted at it. A notable exception to our rule of evaluating only those actions with identifiable

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[1]The interested reader can find more extensive documentation on input data in appendices C, D, and E.

effects and costs involve actions that necessitate the development and use of new water sources (e.g., hatcheries), where we assigned zero cost to the appropriation of the water itself. This assumption may significantly understate the cost of obtaining new water for hatchery programs.

A second modification of the subbasin plans concerns our attempt to evaluate as many realistic combinations of individual propagation actions as possible (each possible combination constitutes a propagation strategy). This differs from the approach of the subbasin planners, who evaluated only a subset of the possible propagation strategies.

Third, we supplemented the information in some of the subbasin plans with more recent data. On the biological side, the more-recent data consists of adjusted hatchery plantings to reflect 1989-1990 hatchery releases, provided by the Fish Passage Center (Fish Passage Center, 1991). On the cost side, we made two adjustments. First, we annualized all capital and operation and maintenance costs at a three percent real discount rate. Second, we updated cost estimates of hatchery-production in the mid-Columbia. Hatchery-related costs in all subbasin plans are based on per-pound capital and annual operation/maintenance costs of $23 and $2.50, respectively. We retained the $2.50 per-pound annual operation and maintenance cost assumption, but assigned higher capital costs of $40 per-pound (for mid-Columbia stocks only), which lies at the low end of estimates provided by hatchery program funders in the mid-Columbia (Klinge, 1991; Nason, 1991).

Finally, we did not evaluate the cost-effectiveness of a number of actions proposed in the subbasm plans that the region has implemented or decided to implement since publication of the plans. We consider any action that has been completed, initiated, or has gone out for final bid and been budgeted for as a sunk cost and therefore an action that forms part of every propagation strategy. For example, we included actions agreed upon in the mid-Columbia PUD Settlement Agreements in all propagation strategies, and thus did not evaluate whether those actions are cost-effective.

Table D.l and Table D.2 in the appendices present the costs and biological effects of the propagation actions for each stock. Combinations of actions have costs that are the sum of the

costs of individual actions, and biological effects that are the product or the sum of the effects of each individual action. For example, the combination of habitat enhancement and groundwater channels for Methow spring chinook, which contribute a 0.1 increase and a 0.2 increase in egg-smolt survival and cost $1,266 and $21,660, respectively, produces a strategy that costs $22,926 and contributes a 0.32 ([1.1 X 1.2] - 1.0) increase in egg-smolt survival.

PASSAGE STRATEGIES

The passage strategies that we analyzed consist of combinations of flow modification, smolt transportation, and predator control. For each set of assumptions that we made regarding the efficacy of passage actions,[2] we modeled at least nine passage strategies. (For one set of assumptions, we included ten passage strategies.) Table 4.1 presents general information on the passage actions included in each of the passage strategies.

The reader should keep several points in mind when viewing Table 4.1. First, the passage strategy labeled CASE00 represents a special passage condition that we used solely for the purpose of calibrating the Deterministic Life Cycle Model (DLCM). It does not represent a separate alternative for evaluation in the cost-effectiveness analysis. Rather, it depicts passage conditions in the mid-1970s to the early-1980s, which corresponds to the time span for which we have actual runsize data. We modeled CASE00 in CRiSP.0 under one set of assumptions (see note 2), input the resulting downstream passage survivals for each stock into the DLCM, and compared the DLCM-generated run size figures with actual run size data, in order to estimate the value of a DLCM parameter that captures natural mortality attributable to the adult phase of the life cycle.[3] Once calibrated with CASEOO, the adult natural mortality parameter in question

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[2]We modeled each passage strategy under a number of different scenarios. Each scenario involves a different set of assumptions regarding transportation survival, predator control effectiveness, and the efficiency of fish guidance systems. See the section on sensitivity testing in this chapter for further details.

[3]The calibration case differs from other cases in the CRiSP.0 files that contain: 1) SAM-generated flows; 2) modulator values to shape monthly average flows from SAM to daily average flows; 3) spill levels and timing at each project; and 4) dam and transportation operation schedules. Most of the parameters that represent different survival characteristics by species (in

TABLE 4.1
Passage Strategies Modeled in Cost-Effectiveness Analysis

STRATEGY NUMBER	FLOWS	PREDATOR CONTROL	TRANSPORTATION
CASE00 (calibration)	historicaI	none	historical
CASE01	NPPC Phase II	none	Partial
CASE02	current	none	partial
CASE03	NPPC Phase II	none	full
CASE04	current	none	full
CASE05	NPPC Phase II	high	partial
CASE06	current	high	partial
CASE07	NPPC Phase II	high	full
CASE08	current	high	full
CASE09*	NPPC Phase II	none	Off

*We modeled CASE09 for only the average fish guidance efficiency, average transportation survival sets of assumptions. See discussion in sensitivity analysis section.

the CRiSP.0 species file) remain identical for the calibration and other cases, although fish guidance efficiencies differ for some projects (see Table E. 1 in Appendix E).

remains constant for all passage strategies, as long as we do not vary our assumptions about the efficacy of passage actions and the life history parameters of salmonids. For each different set of assumptions, however, we re-calibrate and generate a new adult natural mortality parameter.

Second, the passage strategy CASE01 represents a base case strategy, which reflects passage conditions that exist in 1992, or which we assume will be in place in the next five years absent any change in plans due to NPPC actions. The base case strategy thus includes existing flow conditions; current bypass facilities plus bypass installation at Lower Monumental, The Dalles, and all mid-Columbia projects; long screens at Lower Granite, Little Goose, and McNary; improvements in screening at the second powerhouse at Bonneville; and continued smolt transportation at Lower Granite, Little Goose, and McNary, plus transportation at Lower Monumental. Sherer and Fisher (1991) provide estimates for most of the CRiSP.0 parameter values to represent these base case conditions.

Third, the limited amount of data that depict different system operation characteristics necessarily restricted the range of passage scenarios that we could model. For example, different flow scenarios require SAM runs, and at the time of the analysis we possessed only two useful SAM files to use as input in CRiSP.0. These SAM files represent current flows (1991 power year with fifty years of water record) and flows proposed by the Northwest Power Planning Council (1991a) under the Phase II amendments to the Fish and Wildlife Program. To complicate matters, in order to maintain compatibility with these SAM files, we could not model spill that differed from the level and timing of spill specified in the current memorandum of agreement on spill.[4] Additionally, we could analyze only a very limited version of drawdowns (decreases in the elevation of reservoirs in order to decrease water particle travel times) and this only by modeling corresponding flow levels which would produce equivalent water particle travel times. We could not investigate the Idaho drawdown plan and our treatment of drawdowns (e.g., in the John Day

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[4]If we had altered the CRiSP.0 input file responsible for controlling spill, the CRiSP.0 SAM input file would not have reflected the change in spill (i.e., the regulated flows and revenue requirements would not have included the effects of the altered spill).

pool) that rests on the flow-equivalent approach may bias the results in an unknown direction. Furthermore, since we possess cost data only for two levels of predator control (no predator control and high predator control), we could analyze only these two levels. Finally, while we could have evaluated a wide range of transportation levels since we can easily control transportation levels in the relevant CRiSP.0 input files, we modeled only three levels -- full transportation of all smolts at all transportation projects at all times, partial transportation (only sub-yearlings are targeted), and no transportation -- due to time constraints. However, these three levels should bracket the realistic range of transportation efforts, at least in the short-run.

Fourth, our estimates of both the effects and the costs for the passage actions that we modeled rest on limited information. As we noted in Chapter 3, SAM provides an estimate of the marginal revenue requirement of the alternative flow scenario (the difference in revenue requirements between current flow conditions and the Phase II Amendment flows). Estimates of the costs and effects of predator control come from the Northwest Power Planning Council (NPPC, 1991b: 16, 3-3). We assume that the marginal transportation costs of full transportation equal zero, since the U.S. Army Corps of Engineers will need no new barges or facilities (beyond the base case) for full transportation.[5] Estimates of the effects of transportation come from Sherer and Fisher (1991). Transport-benefit ratios (TBRs) calculated from CRiSP.0 runs vary by stock, project, and passage alternative, but averages for yearlings, sub-yearlings, and steelhead across all projects and all strategies are 1.14, 1.49, and 1.23, respectively (for the fish guidance efficiencies and transportation survivals assumed in Sherer and Fisher). Table 4.2 presents species-specific ranges of model-derived TBRs (across eight passage strategies) at each transportation project. These TBR estimates generally lie slightly below those estimates used in the System Planning Model (McConnaha, 1991a, McConnaha, 1991b), and thus reflect less optimism about the relative effectiveness of transportation.

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[5] Collection and barging from Lower Monumental may slightly increase the operating costs of the six barges and five trucks currently used. We ignored this possible additional operating cost, since it is likely to be small. We included, however, an annual $500,000 plus savings gained from eliminating transport in CASE09. (Woodruff, 1992)

TABLE 4.2
Range in Transport-Benefit Ratios at Each Transportation Project, By Species

SPECIES	GRANITE	GOOSE	MONUMENTAL	MCNARY
yearling	1.1 1-1.32	1.12-1.35	1.02-1.33	0.85-1.09
subyearling	1.46- 1.49	1.79-1.81	1.38-1.39	1.28-1.35
steelhead	1.11-1.28	1.17-1.37	1.11-1.34	1.11-1.48

*We calculated the range of TBRs over eight passage strategies, assuming average fish guidance efficiency, average transportation survival, and optimistic predator control effectiveness.

TERMINAL HARVEST[6]

As discussed in Chapter 3, we theoretically could model up to twelve stocks in each subbasin: the three types of stocks possible in each subbasin and fish run (natural stock, supplementation stock, and pure hatchery stock) for each of the four fish runs that we investigated (spring chinook, summer chinook, fall chinook, and steelhead). We furnished a separate parameter for the terminal harvest rate for each of these stocks, although we forced many of the rates within each fish run to be the same. In the calibration case, for example, the values for the terminal harvest rate for the three types of stocks possible (natural, supplementation, and pure hatchery) for each species and fish run could be equivalent if we could not distinguish hatchery-bred fish from naturally-produced fish with the run size data . In cases where we could distinguish the natural stock (e.g., steelhead), the calibration-case rates usually differed for the natural stock relative to the other two stocks.

When we ran the Deterministic Life Cycle Model to produce the estimates of effectiveness for each passage/propagation strategy, we allowed all of the terminal harvest rates for the separate subbasins and fish runs to vary independently from 0 to 80 percent in 20 percent increments. However, we generally did not allow the terminal harvest rates for the three types of stocks possible in each subbasin and fish run (natural stocks, supplementation stocks, and hatchery stocks of Grande Ronde spring chinook, for example) to differ. If we had varied the terminal harvest rates for each of the three types of stocks independently, we would have had to run up to 125 combinations of harvest rates when all three types of stocks existed in the subbasin.

We justify this approach by making three simplifying assumptions. First, in most cases where a pure hatchery stock and supplementation stock coexist in the same subbasin, we assumed that they are subject to the same terminal fishery and thus share the same terminal harvest rate.

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[6]We treat terminal harvest differently than we do propagation and passage actions in that the range of possible terminal harvest rates that we model does not represent any proposed action. Obviously, terminal harvest rates theoretically can be as low a 0 percent and as high as 100 percent. We provide a range of harvest rates for the model to evaluate, and assume that the cost of "implementing" a terminal harvest rate is zero.

Second, in some cases we assumed that the terminal harvest rate on natural fish is zero. This assumption seems safest if the region has accorded priority to the rebuilding of the natural stock and hatchery-bred fish exist in sufficient quantities for harvest. Third, if the run size data indicate equivalent terminal harvest rates among the two or more types of stocks in the calibration case, we assumed that the terminal harvest rates in the cases where we modeled passage strategies also varied together.

MAJOR ASSUMPTIONS

During the development of the database of passage and propagation actions and the subsequent modeling exercise, we made a number of important assumptions about the costs and effectiveness of actions and about the characteristics of the life-cycles of salmonids. We have remarked on some of the assumptions in the preceding sections, but it is useful to reiterate some of these and note other major assumptions here.

Our most obvious kind of assumption relates to the values of model parameters and the biological effects and financial costs of the propagation and passage actions. For the most part, we accepted the estimates of the values (e.g., effectiveness of habitat improvement, cost of predator control) and relationships (e.g., the form of the flow-survival relationship for downstream passage) reported in regional planning documents. Whether our estimates accurately reflect reality poses a question that we cannot answer at present, although we made a limited attempt to assess the importance of parameter uncertainty in our sensitivity analysis.

On the passage side, some of the most important assumptions to bring to the reader's attention include the form and parameterization of the travel time-flow-survival relationship for **downstream passage (see Table E.l); the timing and distribution of the arrival of each stock's** smolts to the mainstem (see table E.2); and the shaping of monthly average flows from SAM into daily average flows by the CBiSP.0 modulator file (we use only a single modulator file from 1990). On the propagation side, important premises include our assumptions that (1) the Beverton-Holt spawner-recruit relationships we use depict the actual spawner-recruit

relationship;7 (2) we can logically separate hatchery and supplementation stocks based on the criteria that out-planted hatchery smolts (i.e., smolts that hatchery managers plant in tributaries away from the hatchery) constitute supplementation stocks, while smolts released directly from the hatchery constitute hatchery stocks; and (3) no net straying occurs among hatchery, supplementation, and natural stocks,

We also assumed that the immediate effects of propagation actions do not depend directly on passage actions or on each other, and that the immediate effects of passage actions do not depend on each other. The ultimate biological effect of any action may be influenced by other actions and thus the desirability of an action may depend very integrally on what other actions the region implements,9 but the immediate, direct effect of any given action does not depend on whether the region undertakes other actions.10

Furthermore, we assumed that the effects of an action do not vary over the projected life of that action. We posited that the region will implement propagation actions once, at time zero, and that the actions' effects will remain constant throughout the planning horizon evaluated in the analysis. We also assumed that the region will take passage actions at time zero and passage-related operating conditions for each strategy (e.g., power demand characteristics and non-environmental passage conditions such as the level of transportation and fish guidance

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7Previous modeling exercises with the Northwest Power Planning Council's System Planning Model also used the Beverton-Holt relationship.

8We sometimes needed to adjust a strategy's effectiveness so that it did not double count the biological effects or costs of two component actions which overlapped in part. For example, in some cases the subbasin plans presented two separate habitat enhancement actions which differed in large part but entailed habitat improvements in some of the same tributary streams. In such cases, we adjusted downwards the effectiveness and costs of any strategy for the subbasin that included both actions.

9For example, the effects of a passage action taken in generation t on the number of smolts in generation t+l may depend on whether the region takes some action to increase carrying capacity in the relevant subbasin.

10An apparent exception to this rule is that predator control contributes relatively less survival improvement with Council flows than with current flows. However, this reflects the difference in travel times between Council and current flows, and not a direct effect of predator control per se.

efficiencies) will remain constant over the planning horizon.11 We further assumed that the region must take an action either in its entirety or not at all (e.g., the region can choose to either improve a subbasin's habitat or not to improve it, but it can not choose to improve only some habitat, unless such an activity constitutes an entirely separate action proposed in the subbasin plans).

We also made some general assumptions about the feasibility of implementing actions and the desirability of the stated objectives. We assumed that staff, equipment, technology, and funds exist in sufficient quantity to implement actions at time zero, and that harvest managers can set harvest rates and control harvest accordingly. We took the utilization and biological objectives stated in the subbasin plans at face value, or in cases such as the Salmon River subbasins we calculated disaggregated objectives from information in the subbasin plans. This implies an equal weighting of the subbasin planners' objectives for each stock, which may not accurately reflect the concern with critical stocks.

Finally, we assumed that the value for the DLCM parameter that represents adult natural mortality (i.e., unknown mortality that we attribute to the adult phase of the life cycle), which we estimated when we calibrated the life-cycle model to run size data from the 1970s and 1980s, remains constant across all years and passage strategies. Thus, if we calculated an adult natural mortality value of 10 percent from the run size data, we assumed the same 10 percent value in all model runs. This stands out as a critical assumption. It means that our calibration run had to reflect assumptions that we made about the efficacy of current processes or management actions, if the processes or actions also existed during the 1970s and 1980s (e.g., bypass systems, barge transportation of smolts   Thus, for instance, if we wanted to model the robustness of our results to an assumption that fish guidance efficiencies (fge) of bypass systems lie 25 percent lower than

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11Our simulations with the downstream passage model reflect the assumption that passage actions are implemented immediately and that their efficacy remains constant over the planning horizon. We provide 50 years of water record in each run of the simulation model in order to generate a distribution of survival values, but we model only one power year (1991) for each of those fifty water years. We use the mean of the 50 passage survivals from the passage simulation for each year of the planning horizon that we model in the Deterministic Life Cycle Model.

we normally assumed, we first had to recalibrate the model to reflect the lower fge assumption; that is, if we introduced more mortality in the calibration run, the parameter that represents the unknown adult natural mortality had to increase in order to yield the observed run size data. When we incorporated the new adult natural mortality parameter value in a current management scenario, this tended to dampen the negative effects associated with the lower fge assumption. In other words, the relative efficacy of management strategies from model runs does not change as readily in response to different assumptions about the efficacy of passage actions as one might initially expect. Of course, this result derives from the fact that we set the adult natural mortality parameter value equal to the adult natural parameter value calculated in calibration model runs that represents conditions 15 to 20 years ago.

GOALS AND OBJECTIVES

We developed the system-wide cost-effectiveness analysis in order to find the set of passage, propagation, and terminal harvest alternatives which will meet a set of defmed objectives at lowest cost. The objectives represent stock-specific numerical targets, which reflect the biological and utilization objectives specified in each subbasin plan.[12] For some stocks, we could not achieve the biological and/or utilization objectives with any strategy. In such cases, we reduced the objectives until it became feasible to meet them. We include details on numerical objectives for each stock in Chapter 5.

In addition to evaluating the trade-offs between costs and different levels of spawning escapement and terminal harvest, we also considered other possible goals and constraints of the fish and wildlife program. For example, program managers may be reluctant to rely on hatchery production to augment a weak stock, because of the potential genetic risk associated with hatchery-dominant programs. We attempted to address this concern by first assessing the genetic risk of propagation actions, ranking them on a simple zero to two scale, with a zero indicating no

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[12]We express biological objectives as average annual spawning escapement levels for each stock, and utilization objectives as terminal harvest levels (sport and tribal) for each stock.

genetic risk above that found prior to implementation of a proposed action, a one indicating a moderate but acceptable risk above the existing condition, and a two indicating an unacceptable risk. Essentially, any action which introduced hatchery fish into a pure natural or wild population received a ranking of two; we ranked all other actions as zero or one. We next assigned a genetic risk of 0, 1, or 2 to each propagation strategy based on the maximum risk associated with any action in the strategy. To approximate the effect of imposing a constraint on maximum acceptable genetic risk, we then constrained the model to use only propagation strategies with a genetic risk less than two. This type of comparison can tell us the effect of placing a high value on conserving the genetic integrity of fish stocks on the composition and choice of cost-effective strategies. Although we did not evaluate additional constraints, other obvious broad goals that we could analyze under this approach include the acceptability of transportation of smolts (i.e., we can exclude transportation as a passage option) and the preference for flow options that many in the region appear to hold.

SENSITIVITY TESTING

Before presenting and discussing the results of our cost-effectiveness analysis in the next chapter, we briefly describe in this section several approaches that we took to investigate the robustness of our results to different values of several passage-related parameters. These parameters concern the flow-survival relationship, transportation survival, the effectiveness of predator control, and fish guidance efficiencies.

The form and parameterization of the flow-travel time-survival relationship make up one of the most controversial elements in many analyses of downstream smolt passage. Some analysts believe that increasing water particle velocity should dominate all other objectives in any passage strategy to improve smolt survival. Others express less confidence that water particle velocities above 1990-1991 levels will necessarily enhance smolt survival. To complicate matters, different relationships probably exist for different stocks of the same species and for different pools. Unfortunately, definitive data to support any position are very limited, so regional analysts have

used a number of different relationships to model downstream smolt survival. (U.S. Army Corps of Engineers, 1992; Giorgi, 1991; Kindley, 1991; McConnaha, 1991b) We utilized both a constant mortality per day relationship (for all species in mid-Columbia pools and sub-yearlings in the Snake and lower Columbia reservoirs) and a broken stick quadratic flow survival relationship. The different flow survival relationships, coupled with variation in the timing of entry by smolts into the mainstem, yielded quite different downstream survival proportions for some stocks. Generally, we used the lowest survival estimate in our analysis. Appendix E provides the parameter values that generated the lower estimates.13

The survival of barge-transported smolts also attracts its share of controversy. While many may agree that smolts survive at higher rates in barges than in slack-water reservoirs, some argue that transported smolts exhibit lower survival rates after release from the barges below Bonneville Dam and lower rates of subbasin adult returns, relative to in-river migrants. We adopted the base transportation survival rates in Sherer and Fisher (1991), which range from a low of 0.44 for sub-yearlings to a high of 0.8 for steelhead. However, we also ran a set of all passage scenarios (excluding the no-transportation strategy CASE09, for obvious reasons) under the assumption that transportation survivals lie 50 percent lower than the base case values for each species at each project.

The effectiveness of predator control is a third passage-related assumption that we explored. Several commentators have argued that the Phase II amendments and associated modeling assumes too much reduction in mortality from predators due to predator control; that is, the predator control proposal over-estimates the reductions in predator-induced mortality. Sherer and Fisher (1991) cite work by Riemann and Beamesderfer to justify a fifty percent decrease in the predator multiplier for reservoir mortality (after a sustained ten to twenty percent harvest of squawfish for a number of years as called for by the Northwest Power Planning Council). We

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13The Northwest clearly would benefit from further work to incorporate the exponential model used by the fishery agencies and tribes and from additional investigation into the effects on downstream survival of variation in the timing of smolt entry to the mainstem.

modeled, for all strategies, both this fifty percent reduction and a less-optimistic twenty-five percent reduction.

Finally, we also explored assumptions about the fish guidance efficiencies of bypass systems. We used the anticipated fish guidance efficiencies reported in Sherer and Fisher (1991) as a base case, but also modeled a twenty-five percent drop in fish guidance efficiencies at all projects for all passage strategies.

CONCLUSIONS

The system-wide cost-effectiveness analysis of mitigation and recovery options in the Columbia basin requires a tremendous amount of data on the costs and biological effects of passage and propagation actions. We obtained most of these data from the subbasin plans developed in the region and the planning documents from the Phase II amendments to the region's fish and wildlife program. Parameter values for the downstream passage model come from CRiSP.0 documentation and analyses conducted by the researchers at the Bonneville Power Administration.

In addition, we have had to make a number of assumptions in order to make the analysis tractable. We have provided documentation on some of the major assumptions in this chapter. Finally, the subbasin planning documents provide the subbasin escapement and terminal harvest objectives that we modeled. However, because the subbasin planners' objectives are somewhat arbitrary, and because decision-makers may want to explore the tradeoffs of different objectives and the cost of attaining them, we varied the escapement and harvest objectives over a wide range in our analysis. We present our results in the next chapter.

CHAPTER 5
OPTIMIZATION MODEL GOALS AND RESULTS

INTRODUCTION

This chapter examines results from our application of the optimization model. Given the limits of the existing data and our incomplete understanding of the dynamics of salmonid populations, we believe strongly that the model provides reasonable and justifiable results. However, we recognize that our approach adopts some arguable assumptions about the efficacy of recovery actions and the behavior of salmonids. Thus, we portray our results as suggestive of general outcomes and illustrative of the possible applications of the optimization model rather than as certain conclusions. To re-iterate a point made in earlier chapters, we developed the model to help decision-makers examine trade-offs among passage and propagation costs, fish production measures, and attributes of fish stocks, and not to provide unambiguous answers as to how they should proceed.

We start with a general discussion of objectives and a quick purview of the results. We next move to a lengthy treatment of results from the model runs in which we tried to achieve 100 percent of the stock and subbasin harvest and subbasin escapement objectives which the subbasin plans specify. We then examine the cost-effectiveness frontiers developed from varying the harvest and escapement objectives over a range of values. We conclude with some brief comments on major points of the analysis.

OBJECTIVES

The subbasin planners established numerical objectives for terminal harvest and natural spawning escapement for each species and run. In many subbasins, we could not determine unambiguously how to establish the separate objectives for hatchery, natural, and supplementation stocks, so we compromised by using two objectives for each subbasin/species combination: one objective for combined terminal harvest (encompassing all of the three types of stocks of the same subbasin/species combination), and one objective for natural spawning escapement. We display our interpretation of the objectives in Table 5.1. We attempted to base the objectives as closely

as possible on the planners' apparent intent, but our numerical objectives probably do not reflect their goals in all cases.

In many cases, the model results suggest that no strategy can meet the numerical objectives for harvest and escapement.[1] Table 5.2 highlights this by showing the percentage of the planners' numerical objective achieved in the modeling exercise for each species in each subbasin. For example, for Cleatwater spring chinook, we could attain the numerical objectives for both harvest and spawning escapement in the model, while for summer chinook on the South Fork of the Salmon River, we could reach only 50 percent of the numerical objective for terminal harvest (18,000, from Table 5.1) and 24 percent of the numerical objective for natural spawning (5,760, from Table 5.1).[2]

We also considered different ways to double the base-case runsize for each stock. In a similar fashion to our efforts with the harvest and escapement objectives, we formulated objectives for each subbasin and run, for natural and hatchery fish combined, and for natural fish only. We define doubling as an increase from the base-case runsize for each subbasin/species combination of 100 percent, where runsize equals the total of **all** harvest (ocean, in-river, and terminal) plus spawning escapement. Table 5.3 exhibits our interpretation of the numerical objectives associated with doubling the runsize for each stock. As with the terminal harvest and escapement objectives, the results of our modeling indicate that many stocks could not meet their runsize objectives. Table 5.4 shows the percentage of the numerical objective associated with

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[1]While the flow regime in the NPPC Phase II amendments produces slightly more fBh than the current (89-90) flow regime for some stocks, the difference is very small, and does not affect the conclusion that the modeled terminal harvest and/or spawning escapement sometimes falls far short of the planners' objectives.

*It is important to emphasize that once we establish the terminal harvest and spawning escapment numerical objectives that at least one passage/propagation/terminal harvest alternative can meet for each stock, we define these numerical objective as the 100 percent level. Therefore, in the subsequent discussion, our definition of the 100 percent level will differ from the planners' 100 percent level for those stocks for which we had to reduce the numerical objective in order to find a feasible solution.

TABLE 5.1
Subbasin Planners' Terminal Harvest and Spawning Escapement Numerical Objectives**

Subbasin	FAC* Harv	FAC* Spawn	SPC* Harv	SPC* Spawn	SSH* Harv	SSH* Spawn	suc* Harv	suc* Spawn
Clear-water	0	0	45000	5000	74000	12000	0	0
Deschutes	4500	6500	6750	1950	8ooo	10000	0	0
Entiat	0	0	500	0	0	0	0	0
Grande Ronde	0	0	4000	10140	9050	17400	0	0
Hood River	100	125	1300	200	4600	2400	0	0
Imnaha	0	0	700	3800	0	0	0	0
John Day	0	0	1050	2975	11250	16875	0	0
Klickitat	0	0	3015	494	3920	2256	0	0
Little White	200	3700	2000	202	0	0	0	0
Methow	0	0	2000	3200	0	0	3000	1458
okanogan	0	0	0	0	0	0	2000	5830
Bear V. (Salmon)	0	0	16000	4500	0	0	0	0
Lemhi R. (Salmon)	0	0	10000	1978	12000	686	0	0
Lower Salmon	0	0	6000	330	10000	664	0	0
Mid-Salmon	0	0	12000	350	2000	1306	0	0
Panther C. (Salmon)	0	0	0	0	8000	58	4000	118
Phsimroi R. (Salmon)	0	0	0	0	33000	209	7000	175
S. Fork Salmon	0	0	0	0	4000	1560	18000	5760
Little Salmon	0	0	10000	805	22000	832	0	0
Upper Salmon	0	0	30000	3018	33000	4656	15000	670
Tucannon	0	0	1152	357	700	1500	0	0
Umatilla	5400	12500	8800	1760	2730	3370	0	0
Wind River	0	0	5000	984	1000	1557	0	0
Wenatchee	0	0	9150	5250	0	0	3000	5600
White Salmon	0	0	500	96	2400	60	0	0
Walla Walla	0	0	2441	2000	7680	3000	0	0

*FAC, SPC, SSH, and SUC are fall chinook, spring chinook, summer steelhead, and summer chinook, respectively
**See text for explanation of terminal harvest and spawning escapment objectives

TABLE 5.2
**Percentage of Planners' Terminal Harvest and Spawning Escapement Numerical
Objectives Met By the Optimization Model****

Subbasin	FAC* Harv	FAC* Spawn	SPC* Halv	SPC* Spawn	SSH* Harv	SSH* Spawn	suc* Harv	suc* Spawn
Clearwater	0	0	100	100	100	100	0	0
Deschutes	100	100	100	100	100	100	0	0
Entiat	0	0	100	0	0	0	0	0
Grande Ronde	0	0	loo	49	100	100	0	0
Hood River	50	100	**100**	100	100	100	0	0
Imnaha	0	0	100	25	0	0	0	0
John Day	0	0	100	100	**100**	100	0	0
Klickitat	0	0	100	100	50	100	0	0
Little White	100	50	100	100	0	0	0	0
Methow	0	0	100	100	0	0	100	100
Okanogan	0	0	0	0	0	0	100	100
Bear V. (Salmon)	0	0	50	50	0	0	0	0
Lemhi R. (Salmon)	0	0	50	50	50	50	0	0
Lower Salmon	0	0	100	100	100	100	0	0
Mid-Salmon	0	0	50	100	100	100	0	0
Panther C. (Salmon)	0	0	0	0	100	100	100	100
Phsimroi R. (Salmon)	0	0	0	0	100	100	100	100
S. Fork Salmon	0	0	0	0	100	100	50	24
Little Salmon	0	0	100	100	100	100	0	0
Upper Sahnon	0	0	100	100	100	100	50	50
Tucannon	0	0	100	100	100	100	0	0
Umatilla	100	100	100	100	100	100	0	0
Wind River	0	0	100	100	100	51	0	0
Wenatchee	0	0	100	100	0	0	100	100
White Salmon	0	0	100	100	100	100	0	0
Walla	0	0	loo	loo	loo	100	0	0

*FAC, SPC, SSH, and SUC are fall chinook, spring chinook, summer steelhead, and summer
chinook, respectively
**See text for explanation of terminal harvest and spawning escapment objectives

TABLE 5.3
Runsize Numerical Objectives***

Subbasin	FAC** runsize (both*)	FAC** runsize (natural)	SPC** runsize (both*)	SPC** runsize (natural)	SSH** runsize (both*)	SSH** runsize (natural)	SUC** runsize (both*)	SUC** runsize (natural)
Clear-water	*0*	0	21853	6466	156549	18390	*0*	*0*
Deschutes	108741	108741	28412	18051	89500	16883	*0*	*0*
Entiat	*0*	*0*	8836	7152	0	0	*0*	*0*
Grande Ronde	*0*	0	7999	4430	30158	17714	*0*	*0*
Hood River	3043	3043	3196	930	16094	9215	*0*	*0*
Imnaha	0	0	3615	2475	0	0	*0*	*0*
John Day	0	0	14796	14796	71486	71486	*0*	*0*
Klickitat	0	0	13543	4579	14335	12432	*0*	*0*
Little White	37980	922	6001	142	0	0	*0*	*0*
Methow	0	0	12282	9321	0	0	86253	70377
Okanagan	0	0	0	0	0	0	98183	70804
Bear V. (Salmon)	0	0	3349	3349	0	0	0	0
Lemhi R. (Salmon)	0	0	559	559	2371	2371	0	0
Lower Salmon	0	0	125	125	11388	2296	0	0
Mid-Salmon	0	0	425	425	4502	4502	0	0
Panther C. (Salmon)	0	0	0	0	305	305	18	18
Phsimroi R. (Salmon)	0	0	0	0	7967	726	15690	65
S. Fork Salmon	0	0	0	0	2485	2485	16448	1207
Little Salmon	0	0	39682	263	14301	4206	0	0
Upper Salmon	0	0	36215	1911	62843	15052	482	482
Tucannon	0	0	5677	2447	4233	1511	0	0
Umatilla	329314	147777	16662	2090	6894	4491	0	0
Wind River	0	0	11491	608	2688	742	0	0
Wenatchee	0	0	45041	17780	0	0	172134	140776
White Salmon	0	0	429	144	13839	228	0	0
Walla Walla	0	0	5019	5019	18266	10467	0	0

*__Both__ refers to combined objectives for natural and hatchery stocks.
**FAC, SPC, SSH, and SUC are fall chinook, spring chinook, summer steelhead, and summer chinook, respectively
***See text for explanation of runsize doubling objectives

TABLE 5.4
Percentage of Runsize Numerical Objectives Met by Optimization Model***

Subbasin	FAC** runsize (both*)	FAC** runsize (natural)	SPC** runsize (both*)	SPC** runsize (natural)	SSH** runsize (both*)	SSH** runsize (natural)	SUC** runsize (both*)	SUC** runsize (natural)
Clear-water	*0*	*0*	100	**loo**	64	76	*0*	*0*
Deschutes	100	100	100	100	100	100	*0*	*0*
Entiat	0	0	100	100	0	0	*0*	*0*
Grande Ronde	0	0	100	100	100	96	*0*	*0*
Hood River	59	59	100	48	100	54	*0*	*0*
Imnaha	0	0	100	81	0	0	*0*	*0*
John Day	0	0	81	81	100	100	*0*	*0*
Klickitat	0	0	100	100	63	64	*0*	*0*
Little White	100	100	100	100	0	0	*0*	*0*
Methow	0	0	100	100	0	0	100	100
okanogan	0	0	0	0	0	0	100	100
Bear V. (Salmon)	0	0	100	100	0	0	0	0
Lemhi R. (Salmon)	0	0	100	100	100	76	0	0
Lower Salmon	0	0	100	100	100	65	0	0
Mid-Salmon	0	0	100	100	100	67	0	0
Panther C. (Salmon)	0	0	0	0	100	100	100	100
Phsimroi R. (Salmon)	0	0	0	0	100	62	100	100
S. Fork Salmon	0	0	0	0	100	80	100	100
Little Salmon	0	0	76	100	100	71	0	0
Upper Salmon	0	0	100	100	100	66	100	100
Tucannon	0	0	100	100	100	100	0	0
Umatilla	76	81	100	100	100	100	0	0
Wind River	0	0	100	100	100	81	0	0
Wenatchee	0	0	56	56	0	0	100	100
White Salmon	0	0	100	100	100	44	0	0
Walla Walla	0	0	100	100	100	100	*0*	*0*

***Both** refers to combined objectives for natural and hatchery stocks.
**FAC, SPC, SSH, and SUC are fall chinook, spring chinook, summer steelhead, and summer chinook, respectively
***See text for explanation of runsize doubling objectives

runsize doubling for each stock that the modeling exercise could achieve.3

In addition to these numerical objectives, we also investigated whether the imposition of objectives related to the genetic integrity of salmon populations influences the cost and composition of recovery strategies. More specifically, we modeled the possibility that a crude constraint on genetic risk would increase costs or alter the preferred actions, by curtailing new hatchery operations in reaches with wild stocks. As a final step in the analysis, as noted earlier we conducted a sensitivity analysis to determine whether changing our assumptions about the effectiveness of two passage-related actions affects the composition and cost of the preferred passage strategy. We modeled both average (designated as **_average_** passage sensitivity) and low (designated as low passage sensitivity) assumptions about fiih guidance efficiencies (fge) in bypass systems, transportation survival, and predator control **effectiveness.**[4] We discuss conclusions from our sensitivity analysis as well as more-detailed results from our modeling of the numerical objectives and the genetic constraint in the following sections.

RESULTS: 100% OF OBJECTIVES

Table 5.5 through Table 5.8 display the results from model runs. The tables display how the costs and composition of the recovery alternatives (i.e., the preferred actions) vary as we alter our assumptions about the efficacy of passage actions, introduce a genetic constraint, or change our emphasis between terminal harvest or natural spawning escapement. We first discuss how the costs of the recovery alternatives change as we introduce constraints and then examine how the composition of the recovery alternatives shift.

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[3]Once we establish the runsize doubling numerical objective for each stock that at least one passage/propagation/terminal harvest alternative can attain, we define this numerical objective as the 100 percent level. See note 2.

[4]As detailed in Chapter 4, the low passage sensitivity case represents fge 25 percent below average fge, transportation survivals 50 percent below average transportation survivals, and predator control effectiveness 50 percent below average predator control effectiveness. Table E. 1 furnishes the average values for these parameters.

TABLE 5.5
Optimization Results for Different Passage Sensitivities,
Objectives, and Acceptable Levels of Genetic Risk*

Scenario Number	Passage Sensitivity	Objectives	Genetic Risk	Passage Strategy	Passage Cost	Prop. cost	Total cost
1	Average	Harvest Only	No Constraint	8	9.0	3.7	12.7
2	Average w/ Council Flow	Harvest & Natural Spawning Escapement	No Constraint	7	79.0	10.0	89.0
3	Average	Harvest & Natural Spawning Escapement	No Constraint	8	9.0	10.0	19.0
4	Average	Harvest & Natural Spawning Escapement	Low Genetic Risk	8	9.0	10.0	19.0
5	Low FGE, etc.	Harvest & Natural Spawning Escapement	No Constraint	8	9.0	13.9	22.9
6	Average	Runsize Doubling	No Constraint	8	9.0	14.9	23.9
7	Average (Planners Preferred)	Harvest & Natural Spawning Escapement	No Constraint	8	9.0	18.0	27.0

*Costs are in millions of dollars, annualized at a three percent real discount rate.
**Sensitivity runs for passage included "average" assumptions regarding the efficacy of fish guidance efficiencies (fge), transportation survival, and predator control, and "low" assumptions, in which we reduced fish guidance efficiencies by 25 percent, transport survival by 50 percent, and predator control efficacy by 25 percent.

TABLE 5.6
Propagation Costs for 100% Solutions*

Subbasin	Average fge Assumption**	Runsize Doubling	Planners' Strategy	Low Fge Assumption**
Clearwater	0.205	0.370	0.845	0.205
Deschutes	0.279	0.474	0.66 1	0.301
Entiat	0	0.08 1	0.027	0
Grande Ronde	2.709	1.578	2.030	2.709
Hood River	0.313	0.238	0.245	0.313
Imnaha	0.330	0.234	0.563	0.563
John Day	0.739	0.799	0.825	0.739
Klickitat	0	0.039	1.254	0
Little White	0.006	0.006	0.346	0.006
Methow	0	0.052	0.708	0.173
Okanagan	0.005	0	0.334	0.299
Bear V. (Salmon)	0.188	0	N/A	0.189
Lemhi R. (Salmon)	0.867	0.679	0.867	0.867
Lower Salmon	0.188	0.882	N/A	0.189
Mid-Salmon	0.867	0.679	N/A	0.867
Panther C. (Salmon)	0.469	0.036	0.699	0.469
Pahsimeroi R. (Salmon)	0	0.664	0.664	0
S. Fork Salmon	0.380	0.380	0.229	0.569
Little Salmon	0.189	0.807	0.807	0.189
Upper Salmon	0.716	2.225	0.724	0.716
Tucannon	0.017	0.022	0.069	0
Umatilla	0.419	3.169	3.169	2.842
Wind River	0.495	0.556	0.709	0.495
Wenatchee	0	0	0.185	0.582
White Salmon	0.017	0.035	0.469	0.017
Walla Walla	0.633	0.856	1.600	0.633
Total Propagation Cost	10.03 1	14.862	18.032	13.932

*Costs are in millions of dollars, annualized at a three percent real discount rate. The passage strategies chosen by the optimization model for each entry were current conditions (1989-1991 flows with planned improvements to bypass and transport facilities) and predator control, with an annual cost of 9.0 million dollars.

**Sensitivity runs for passage included "average" assumptions regarding the efficacy of fish guidance efficiencies (fge), transportation survival, and predator control, and "low" assumptions, in which we reduced fish guidance efficiencies by 25 percent, transport survival by 50 percent, and predator control efficacy by 25 percent.

TABLE 5.7
Preferred Propagation Actions For Selected Subbasins

Subbasin	Action Description	Average fge	Runsize Doubling	Planners' Strategy	Low fge
Grand Ronde	improve hatchery effectiveness	X	X	X	X
Grand Ronde	improve habitat	X	X	X	X
Grand Ronde	add 2 million hatch smolts	X		X	X
Grand Ronde	supplement w/ 1 million hatch smolts	X			X
Grand Ronde	improve habitat	X	X	X	X
Klickitat	remove barrier at Castile Falls		X	X	
Klickitat	redesign ladder at Klickitat Hatchery		X	X	
Klickitat	reduce sediment from Big Muddy Ck.; enhance riparian habitat			X	
Klickitat	remove barrier at W. Fork Falls			X	
Klickitat	remove barrier at L. Klickitat Falls			X	
Klickitat	add 2.4 million smolts (action 2)			X	
U. Salmon	enhance habitat			X	
U. Salmon	add 2.8 million smolts		X	X	X
U. Salmon	add 1 million smolts	X		X	X
U. Salmon	add 2.5 million smolts		X		
Umatilla	enhance flow		X	X	X
Umatilla	add 600,000 smolts		X	X	
Umatilla	provide headwater storage				
Umatilla	improve adult and juvenile passage				
Umatilla	enhance instream and riparian habitat	X	X	X	X
Walla Walla	improve adult and juvenile passage		X	X	
Walla Walla	enhance instream and riparian habitat		X	X	
Walla Walla	initiate 100,000 smolt release (3b)	X	X	X	X
Walla Walla	headwater storage to improve flow				
WaUa Walla	produce 500,000 hatchery smolts	X		X	X
Walla Walla	produce 100,000 hatchery smolts	X		X	X
Walla Walla	improve adult and juvenile passage			**X**	
Walla Walla	enhance instream and riparian habitat	X	X	**X**	X
Walla Walla	enhance flows using headwater storage				

TABLE 5.8
Cost of Attaining Terminal Harvest/Spawning Escapement Objectives,
by Percent of Objective*

Percent of Objective**	Passage Cost***	Propagation Cost***	Total Cost***
100	9.0	10.0	19.0
95	9.0	9.5	18.5
90	9.0	9.1	18.1
85	9.0	6.1	15.1
80	9.0	6.0	15.0
75	9.0	6.0	15.0
70	9.0	5.4	14.4
65	9.0	5.2	14.2
60	0.0	6.0	6.0
55	0.0	5.6	5.6
50	0.0	5.3	5.3

*For average assumptions regarding the efficacy of fish guidance efficiencies (fge), transportation survival, and predator control. See text for explanation.
**Percent of the terminal harvest and spawning escapment numerical objectives specified in the subbasin plans. See text for explanation.
***Costs are in millions of dollars, annualized at a three percent real discount rate.

Total Costs

Table 5.5 summarizes the results for seven scenarios or combinations of biological objectives, passage sensitivity, and genetic risk. Total annualized costs for the seven scenarios range from $12.7 million to $89 million per year, with these total costs disaggregated into passage and propagation expenditures as shown. Several features of the results deserve mention. First, the optimization model almost always selects passage strategy 8, which includes 89-91 flows, increased transportation levels, and increased predator control. Only in scenario 2, where we forced the model to select Council Phase II flows, do current flows not appear. In comparing scenarios 2 and 3, which are identical in their passage sensitivities, numerical objectives, level of acceptable genetic risk, and preferred propagation strategy,5 we can see that the requirement for Phase II flows appears to yield a system-wide strategy to meet the planners' objectives that costs $70 million more annually than the system-wide strategy identified by the optimization model. This result may rest on the different assumptions inherent in the cost-effectiveness models (particularly the relationship between reservoir flows and smolt survival in CRiSP.O), but it nonetheless strongly suggests that additional empirical work on the relationship between flows and survival is warranted. Given the tension among the popularity of increased flows, the apparent large cost and limited effectiveness of these flows, and the biological importance of enhancing survival for many stocks above Bonneville Dam, the region clearly needs to continue and extend its investigation of downstream survival.

Second, the addition of a constraint on acceptable genetic risk appears to make little difference in the system-wide cost-effective strategy. In Table 5.5, scenarios 3 and 4 are identical, except for the addition of a constraint on genetic risk in scenario 4 (see Chapter 4 for details). After initially imposing the genetic constraint (i.e., no new hatchery releases to wild stocks) to model scenario 4, we saw that spring chinook in the Hood River, Bear Valley (in the Salmon River), and the Lemhi River, had no analyzable propagation alternatives (with costs and biological

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5The preferred propagation strategy identified by the optimization model in scenario 2 contains exactly the same propagation actions as the preferred propagation strategy for scenario 3, although Table 5.5 does not show this directly.

effects) with acceptable genetic risks, and that passage strategies alone could not meet the objectives for these stocks. When we relaxed the genetic risk constraint for these stocks, however, the optimization model selected the same passage and propagation strategies for scenarios 3 and 4. In other words, except for the three stocks with no propagation alternatives that did not introduce some genetic risk, the constraint on genetic risk did not affect the composition or cost of the least-cost, system-wide strategy.

Third, in contrast to the minor effects of the genetic risk constraint, our alteration of assumptions regarding the efficacy of passage actions substantially affected the costs and choice of preferred propagation strategies.[6] In Table 5.5, scenario 5 differs from scenario 3 only in the more pessimistic assumptions concerning fish guidance efficiencies (fge) and transportation survival (see Chapter 4 for details) included in scenario 5. However, the different assumptions result in considerably higher costs for propagation strategies ($13.9 million per year versus $10.0 million). In addition, although we do not show this in Table 5.5, we had to reduce the objectives for Tucannon steelhead, Bear Valley spring chinook, and Pahsimeroi summer chinook by 10 to 50 percent in order to model scenario 5, since under the low fge of scenario 5, no combinations of propagation and passage could meet their biological objectives.

Fourth, our analysis of the preferred propagation strategies identified in the subbasin plans indicated that the planners' strategies cost considerably more and sometimes do not yield harvest and spawning escapement levels that meet the objectives. In scenario 7, we evaluated the subbasin planners' preferred propagation strategies in combination with each of the 8 passage strategies and allowing the terminal harvest rates to vary in the same fashion as in the other model runs (0 to 80 percent in 20 percent increments). As Table 5.5 displays, the cost of the planners' preferred propagation strategies ($18.0 million annually) greatly exceeds the cost of the preferred propagation strategies identified by the optimization model ($10.0 million annually in the comparable case, scenario 3). Additionally, the planners' preferred strategies did not meet the terminal harvest and spawning escapement objectives used in the other analyses (i.e., scenarios

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[6]The preferred passage strategies remain robust, however.

2,3,4, and 5) for several stocks.[7]

Finally, our evaluation of the goal of doubling the runsize of each stock indicates that attainment of the goal will entail higher costs. Scenario 6 in Table 5.5 summarizes the results of modeling this goal. The model selects a substantially higher-cost group of propagation strategies in comparison to the terminal harvest/spawning escapement objectives in scenario 3 ($14.9 million versus $10.0 million per year), and again selects passage strategy 8. The runsize doubling goal entails substantially lower terminal harvest rates for most stocks, since reducing harvest rates increases total runsize at no cost. The next section provides more details on how the propagation strategies differ among scenarios.

Distribution of Propagation Expenditures

As just indicated, the total cost of propagation strategies can vary widely among the different scenarios that we modeled, from $10.031 million annually to $18.032 million annually. However, the variation becomes even more pronounced when we look at the disaggregated propagation strategies for each individual subbasin. Table 5.6 clearly shows both that the cost of the preferred propagation strategy for any given subbasin can vary greatly among scenarios, and that the cost of the propagation strategies among different subbasins can vary greatly within any given scenario. As an example of the former variation, we can see in Table 5.6 that the Klickitat has a propagation cost of zero for two scenarios, and a maximum propagation cost of $1.254 million for the planners' preferred strategy. As an example of the between-subbasin cost variation, in the average fge scenario five subbasins have a propagation cost of zero (and therefore evidently require no propagation actions to achieve their terminal harvest and escapement objectives), five subbasins require propagation strategies that cost between $500 thousand and $1 million annually,

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[7]The subbasin planners identified preferred strategies for each subbasin, but we could analyze only those actions in the preferred strategies that had usable economic and biological data. Therefore, for some subbasins, we had to exclude some actions which were components of the preferred strategies. For example, we could not analyze any of the actions in the planners' preferred strategies in three subbasins (Bear Valley, the Lower Salmon, and the'mid-Salmon), due to the lack of biological and/or cost data. .

and one subbasin has a cost that exceeds $2.7 million annually. When we make more pessimistic assumptions regarding the efficacy of passage actions (the rightmost column of Table 5.6), four subbasins still require no propagation actions, eight require expenditures between $500 thousand and $1 million annually, and two subbasins have costs that exceed $2.7 million annually.8

We show the actions associated with the propagation strategies for five subbasins with significant propagation expenditures in Table 5.7. (Appendix D provides details on the actions' costs and biological affects.). An X in the row and column entry for each action and scenario indicates that the model solution for the scenario included the action identified in the row, while a blank indicates its exclusion. The table highlights several points. First, recall from our earlier discussion that the average fge scenario and the planners' strategies scenario share the same set of terminal harvest and spawning escapement numerical objectives for each stock, even though the planners' strategies did not meet the numerical objectives for several stocks, and the planners recommended propagation strategies that cost more in total than those suggested by the optimization model. For example, as Table 5.7 shows, the planners suggested six actions in the Klickitat, while the optimization model identified the need for no propagation actions. Similarly, the planners recommended three actions in the Upper Salmon, while the preferred propagation strategy identified by the optimization model included only one action. This pattern does not hold universally, since the optimization model identified a strategy with more propagation actions in the Grand Ronde than did the planners. However, the selection of additional actions in the Grand Ronde occurs because the additional action (adding hatchery smolts) is required to meet the planners' numerical objectives.

A second interesting feature displayed in Table 5.7 is that six of the twenty-nine actions shown in the table are included in all four scenarios. The six include an action to improve **hatchery effectiveness in the Grand Ronde, two habitat enhancement actions in the Grand Ronde,**

8In Table 5.6 the alert reader may note that the Tucannon requires a modest amount of propagation activity under the average FGE scenario, but none under the low-FGE scenario. This anomaly obtains because we had to reduce the objectives for Tucannon summer steelhead in order to find a feasible solution. We obviously reduced them a bit too far.

a supplementation action in the Walla Walla, a habitat enhancement action in the Walla Walla, and a habitat enhancement action in the Umatilla. The robustness of these actions over the four scenarios suggests that the region should investigate these six actions very thoroughly, since both the planners and the optimization model selected them across a range of objectives and assumptions.

A final point raised by Table 5.7 is that the optimization model never selects three of the options (Walla Walla headwater storage, Umatilla headwater storage, and Umatilla passage improvements) in any of the scenarios. These actions cost a lot of money and seemingly can boast only limited biological effectiveness. While this does not mean of course that the region should abort all consideration of these projects, their apparent limited efficacy and high costs suggests that these actions require more extensive study and justification.

COST-EFFECTIVENESS FRONTIERS

Table 5.8 and Table 5.9 show the costs of meeting varying percentages of the terminal harvest/spawning escapement numerical objectives (using scenario 2) and the runsize doubling numerical objectives, respectively. We varied the percentages from 50 to 100 percent in five percent increments. Note that because of the way we defined the objectives, the table entries mean different things for terminal harvest/spawning escapement and run-size doubling. For example, the 50 percent level for terminal harvest/spawning escapement in Table 5.8 indicates that we have reduced the numerical objectives for each stock by 50 percent. For the runsize doubling objectives in Table 5.9, however, the 50 percent level indicates a numerical objective that equals the base case runsize for each stock.9 (The 75 percent level for the runsize doubling objectives

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9The numerical objective associated with the 50 percent of the doubling goal level should agree with the calibration-case runsize for all stocks, since the calibration case serves as the reference point for the runsize doubling goal. Furthermore, the cost of attaining this level should equal zero, because the cost of the calibration and base cases is zero by definition. However, Wind River steelhead had slightly higher downstream passage survival under historical conditions (during the calibration period) than they do today. Therefore, in order to achieve the same runsize in the future as this stock enjoyed in the years represented by the calibration case, the model selects a propagation strategy for the Wind River which includes actions that cost about $400 thousand per year; hence the cost of meeting the base case run size slightly exceeds zero.

TABLE 5.9
Cost of Attaining Runsize Doubling Numerical Objectives,
by Percent of Objective*

Percent of Objective**	Passage Cost***	Propagation Cost***	Total Cost***
100	9.0	14.9	23.9
95	9.0	11.6	20.6
90	9.0	10.9	19.9
85	9.0	9.6	18.6
80	9.0	8.7	17.7
75	9.0	7.4	16.4
70	0.0	11.0	11.0
65	0.0	8.7	8.7
60	0.0	7.6	7.6
55	0.0	3.0	3.0
50	0.0	0.4	0.4

*For average assumptions regarding the efficacy of fish guidance efficiencies (fge), transportation survival, and predator control. See text for explanation.
**Percent of the runsize doubling goal expressed by the Council. See text for explanation.
***Costs are in millions of dollars, annualized at a three percent real discount rate.

indicates an objective that represents a 50 percent increase in runsize from the base case [(0.75-0.50)/0.50], and the 100 percent level an objective that represents a 100 percent increase [i.e., doubling] in runsize from the base case [(l.OO-0.50)/0.50]).

We display the cost-effective frontiers for the terminal harvest/spawning escapment objectives and runsize doubling objectives in Figure 5.1, Figure 5.2, and Figure 5.3. From Figure 5.1, we can see that the costs of attaining the terminal harvest/spawning escapement objectives rise sharply at two points. The sharpest increase -- $8 million per year -- occurs when the number of fish for terminal harvest and spawning escapement for each stock increases from 60 percent to 65 percent of the number originally specified in the subbasin plans. This increase results from the introduction of an expensive predator control action. The other sharp increase -- $3 million per year -- occurs when the number of fish for terminal harvest and spawning escapement for each stock increases from 85 percent to 90 percent of the number originally specified. This increase results from a large increment in propagation costs.

Figure 5.2 shows that the costs of attaining runsize increases above the base case also rise most sharply at two points. Again, the sharpest increase -- $5 million per year -- occurs with the introduction of predator control, although this takes place when the number of fish increases from the 70 percent level to the 75 percent level. As indicated above, because of the way we defined the objectives this represents a change from a 40 percent increase from the base case runsize to a 50 percent increase from the base case runsize. The next sharpest increase -- $3 million per year -- occurs from the 95 percent level to the 100 percent level. This represents a change from a 90 percent increase from the base case runsize to a 100 percent increase (doubling) from the base case runsize.

Figure 5.3 provides an overlay of the cost-effectiveness frontiers for terminal harvest/spawning escapement and runsize increases. From this, we see that the frontiers cross each other twice: once between 55 percent and 60 percent, and again between 70 percent and 75 percent. We also can see that the frontier depicting runsize increases above base case runsizes consistently lies above the harvest/escapement frontier from the 75 percent level to the 100
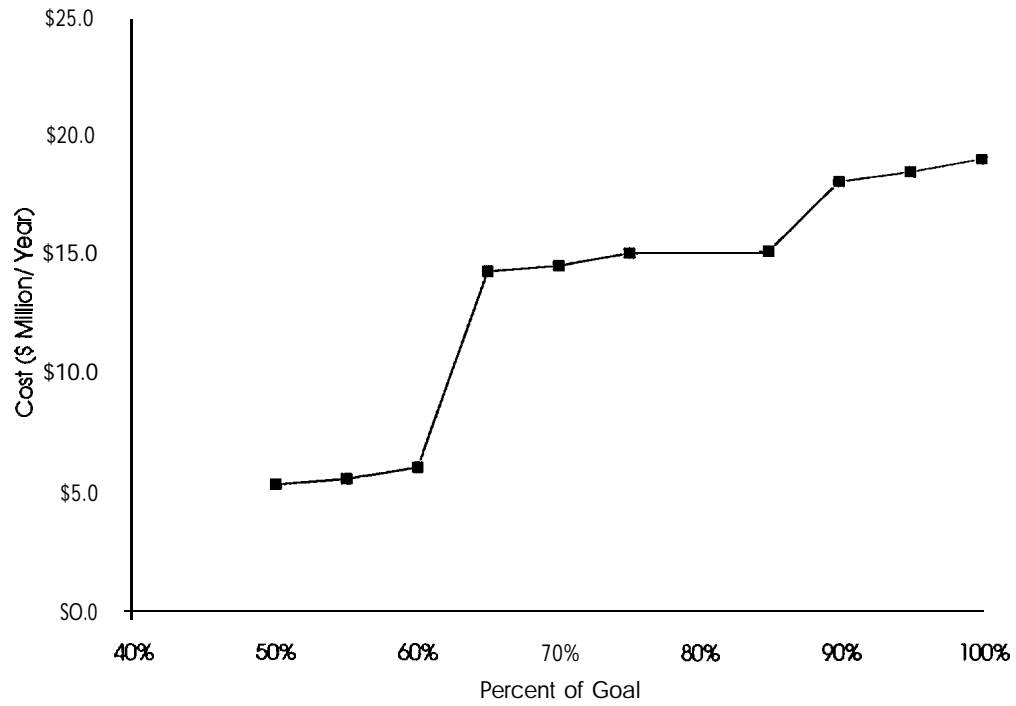
Figure 5.1. Terminal Harvest/Spawning C/E Frontier

Figure 5.2. Runsize Doubling C/E Frontier

Figure 5.3. Combined Runsize Doubling - Spawning/Terminal Harvest Frontiers
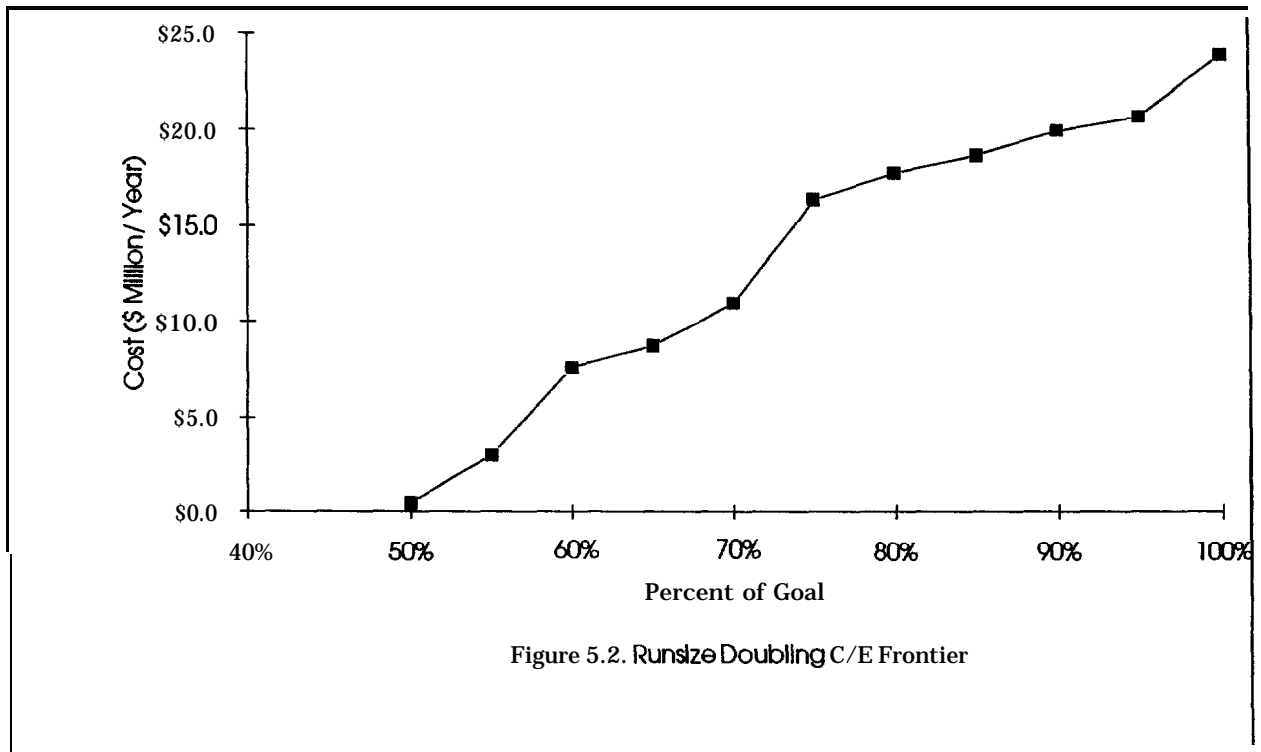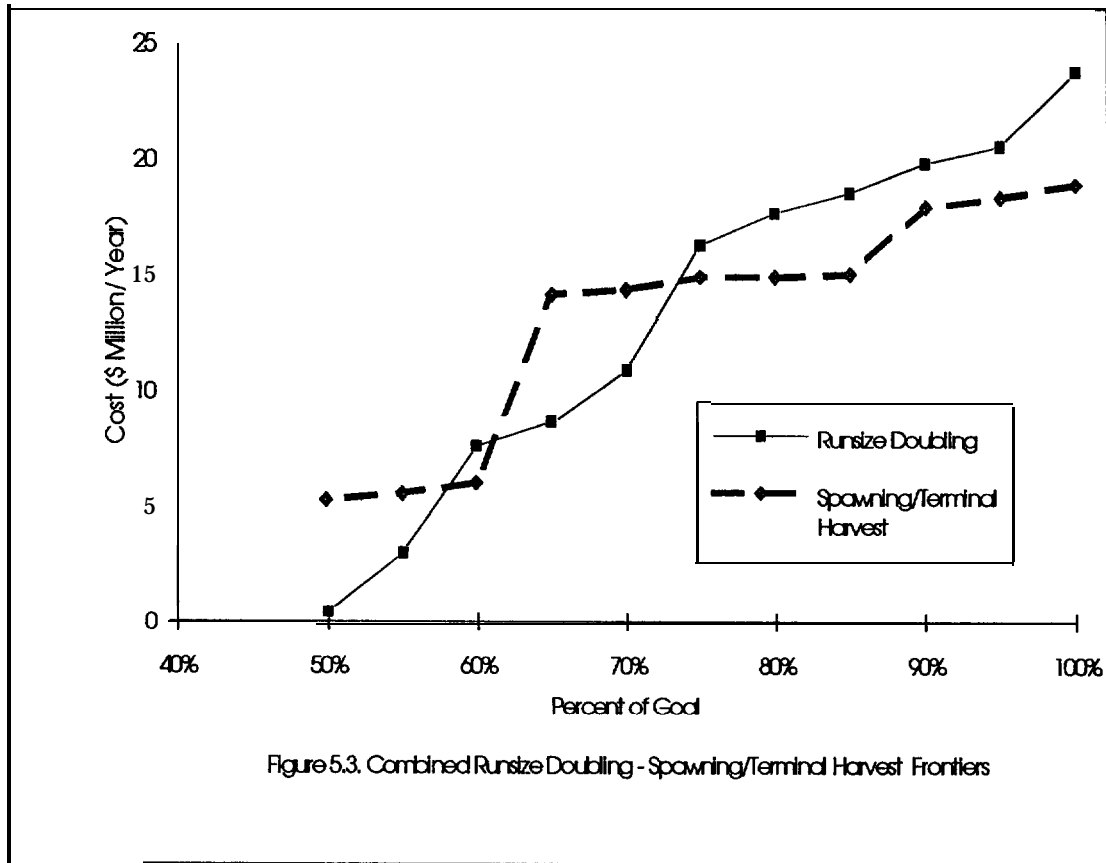
percent level. Taken together, this suggests that while increasing the size of the runs likely will cost more than increasing terminal harvest and spawning escapement as one approaches likely ranges for the two kinds of objectives, the attainment of the proportional runsize increases sometimes may cost less than attainment of the stock-specific numerical objectives for terminal harvest and spawning escapement. An approach for setting objectives that is based on equal proportional increases above one reference case (i.e., historical run sizes) thus may not be entirely consistent with an approach that is based on equal proportional increases above another reference case (*i.e.*, terminal harvest and spawning escapement objectives set by subbasin planners). In other words, not only can the composition and cost of least-cost recovery alternatives depend very much on what reference case is chosen for setting objectives, but objectives defined on an apparently less-ambitious reference case may ***not always*** yield a recovery alternative that entails fewer recovery actions and lower costs.[10]

As a final point, the shape of the cost-effectiveness frontiers differs somewhat from expectations, in that the marginal cost of each 5-percent increase in the number of fish does not always increase as the number of fish increases.[11] (Each of the three figures that depict cost-effectiveness frontiers displays this clearly.) One would expect each 5 percent increment to cost no less than the previous 5 percent increment, because if it cost less (to go from 65 percent to 70 percent than from 60 percent to 65 percent, for example) it seems as if the optimization model would have chosen the less-costly 5 percent increment earlier. However, the actions evaluated in the analysis are lumpy; that is, one can either implement an action in whole or not at all. Passage actions exhibit this lumpiness most clearly. This appears most evident in moving from the 60 percent level to the 65 percent level of terminal harvest/subbasin escapement, where we need to add an expensive predator control action to reach the 65 percent level. Once we include this

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[10]The counter-intuitive result of a less ambitious reference case requiring more actions and higher costs at certain levels of effectiveness prevails when the allowed tradeoffs among objectives for different stocks in the less ambitious reference case are more restrictive.

[11]If marginal costs increased as the number of fish increased, the lines connecting the points on the cost-effectiveness frontier would become progressively steeper as we moved from left to right on the frontier.

action, we need no additional passage actions beyond the base case passage actions. Instead, propagation actions, which generally cost less than passage actions, can drive further increases in the numbers of fish.

SUMMARY

The cost-effectiveness analysis presented in this report can provide useful information to decision makers about how to achieve a set of objectives related to recovery planning for salmonids at least cost. As this chapter clearly shows, the composition and financial cost of the least-cost recovery alternatives identified in the analysis depend on the number of fish specified in an objective, the type of objective (e.g., runsize doubling objectives **verses** subbasin planners' objectives), constraints (e.g., genetic risk), and assumptions regarding the behavior of salmonids and the efficacy of recovery actions (e.g., different estimates of transportation survival). Furthermore, the analysis demonstrates vividly that any analysis which excludes portions of the fish life-cycle, or which focuses exclusively on a few stocks, may miss both fish-production and cost-saving opportunities.

Several results discussed in this chapter and points made elsewhere in this document deserve reiteration and expansion here. First, the consistency with which the optimization model chooses passage strategies using current (1989-9 1) flows and rejects those calling for increased flows furnishes a strong argument for much more extensive research on the relationship between flow and survival. While we recognize that the flow-survival relationships that we included in our model have not gained acceptance in some quarters, the tremendous cost and potentially limited efficacy of measures to increase flows trumpets the need for further work to justify proposed flow measures. Arguments that enhanced flows will more nearly approximate historical (i.e. pre-European settlement) conditions do not provide evidence in and of themselves that such flows will significantly improve survival. Fortunately, it appears that further work on the relationships between flow and survival, as well as other work in other critical areas related to passage and

propagation measures, is proceeding. [12]

Second, and related to this, while we recognize that other characteristics or objectives associated „with flow enhancement or drawdown (i.e., those not directly related to biological effectiveness or costs) may make such measures appealing or necessary, it seems desirable to state these other characteristics or objectives up front in order to facilitate examination of the best way to achieve them. For example, the muted but persistent argument that flow enhancement provides a mechanism for distributing the costs of recovery actions around the region (by incorporating the costs into the electric power rate base) may represent a legitimate objective, but unless we clearly express the desire to spread the costs and construct a vision of what a desirable distribution is, we may miss more appealing opportunities to achieve the distribution of costs and fish levels that we seek. More generally, clear articulation of possible objectives by interests in the region will facilitate analysis and help promote the development of relevant information for policy makers who need to explore the trade-offs between different objectives.

Third, it appears that the objectives set by the subbasin planners lie close to the upper limits for many stocks, given the propagation and passage actions modeled. This suggests that if interests within the region desire fish production increases greater than the levels established in the subbasin plans or above the runsize doubling objectives, they will need to develop additional actions beyond those presented in the subbasin plans and in regional discussion of passage alternatives.

Fourth, the modeling exercise highlights the need for documentation of all types of passage and propagation actions. We omitted many passage and propagation actions from the cost-effectiveness analysis because we had no estimates of their effectiveness (or costs in a few cases). In some cases this reflects an understandable lack of information on the effects of experimental actions. It is precisely for such cases that the region should commit itself to rigorous monitoring of the effects of experimental actions. However, in situations in which proposed

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[12]The Skalski and Giorgi (1992) proposal to estimate smolt travel time and mortality provides an obvious example of such efforts.

passage or propagation actions follow directly from established practices, proponents of the actions should provide more documentation on the intended effects and consequences of the actions. Funders in particular should require clear justifications for proposed actions. Even in the unlikely occurrence that the region is willing to commit an infinite amount of money to recovery of salmonids, some actions will preclude or obviate others (e.g., removal of a barrier to adult migration may eliminate the need for an adult ladder), while other actions will take precedence (a subbasin may require removal of a barrier before enhancement of habitat). Without documentation of an actions anticipated effects, decision makers may lack useful guidance on what actions to implement.

Finally, the results suggest that regional policy makers may need to decide whether they want to adopt (or whether the Regional Power Act requires) least-cost, system-wide planning for fish and wildlife. Analysts and planners have concentrated a significant amount of separate effort on subbasins within the Columbia Basin and on passage alternatives, yet the combination of results from subbasin analyses and passage analyses conducted separately does not necessarily lead to system-wide least-cost planning. As we stated elsewhere in this paper, a focus on propagation actions in isolation from passage actions in all likelihood will not yield a system-wide, least-cost set of management actions. Given the limited financial resources, finite amount of political will, and the tremendous need to enhance survival of salmonids in the Columbia basin, it seems evident to us that the region can not afford to miss the opportunity for effective least-cost, system-wide planning.

APPENDIX A
DETERMINISTIC SIMULATION MODEL

INTRODUCTION

This appendix describes the deterministic simulation model in considerably more detail than did Chapter 3. In contrast to the optimization model, the simulation model is concerned with one subbasin, species, and propagation/passage option at a time; interactions among species and subbasins are not included here. In this chapter, we first show how individual stocks are classified, and describe the possible interactions among subdivisions of related stocks. Next, we conceptually relate how the deterministic simulation handles each stage of the life cycle, from spawning and rearing to subbasin harvest (Chapter 3 described input data sources). We then outline the model equations in detail. We conclude with a description of the model outputs used, in turn, as inputs to the optimization model described in Appendix B. The reader may wish to consult Figure A. 1, which depicts the relationships among the various life stages, before proceeding to the remainder of this appendix.

STOCK CLASSIFICATION AND INTERACTION

Stocks are divided into three categories for purposes of the deterministic simulation model: pure hatchery stocks, pure natural stocks, and supplementation stocks. Essentially, the determination is based on two criteria: whether a fish is produced naturally or in a hatchery, and where the fish subsequently spawns as an adult (see Figure A.2). Any given species or run (the model includes steelhead, spring chinook, summer chinook, and fall chinook runs) can therefore have at most three stocks per subbasin, as defined above. Note that although the deterministic simulation overall considers multiple stocks of the each species or run, and the inter-stock interactions within each subbasin, it does not include inter-species, inter-run, or inter-subbasin interactions; these are handled in the optimization model.

Within this context, the simulation model looks at three basic types of stock interaction. First, broodstock take for supplementation is directed jointly at natural and supplementation

stocks. Second, terminal harvest may be directed at either hatchery-spawned individuals, naturally-spawned individuals, or both types jointly. Finally, hatchery-produced juveniles (i.e., immature fish prior to or at the smolt stage) may be introduced into the naturally-produced juvenile population. Note that this classification scheme says nothing about how the stocks behave outside the subbasin. Their behavior, in both the model and in reality, may be identical or quite different with respect to downstream passage, ***ocean*** survival and harvest, ***et cetera.***

Pure Hatchery

We define pure hatchery stocks as those produced in hatcheries and subsequently spawned in hatcheries. In essence, pure hatchery stocks are most nearly like traditional hatchery operations. We assume they have no subbasin-level interaction with natural or supplementation fish; that is, they are not allowed to spawn naturally, broodstock is taken from the pure hatchery stock only, they are harvested separately (at least within the subbasin), and they are not outplanted until they reach the smolt stage, so there is no interaction among juveniles of hatchery stocks and natural or supplemented stocks. Note that this does not preclude the possibility of interactions ***outside*** the subbasin, including mixed-stock harvest and similar or identical results for downstream passage.

As with any model, our representation of fish behavior is a simplification of reality. Obviously, even pure hatchery stocks must get their initial broodstock from another hatchery or from natural-origin fish, and natural or supplementation fish are sometimes used as broodstock for pure hatchery operations. We assume these interactions are small enough that they can be ignored. Moreover, some straying of pure hatchery fish into naturally-spawning populations must certainly occur for most or all hatchery stocks. We assume there is no ***net*** straying of hatchery fish (incoming strays are balanced by outgoing strays).

Pure Natural

We define pure natural fish as those which are produced naturally and which spawn

naturally in the stream, regardless of where their parents were produced. A pure natural stock, as represented here, does not interact with pure hatchery fish, but may provide broodstock for one or more supplementation stocks. Furthermore, we assume that terminal harvest on natural stocks is physically separated from terminal harvest on pure hatchery stocks, but that natural and supplementation stocks are at least potentially subject to the same terminal fishery (their harvest rates may differ where naturally-spawned fish can be distinguished from hatchery-bred fish).

Supplementation

A supplementation stock is produced in a hatchery but spawns naturally in the stream, interbreeding with pure natural fish. Thus, the offspring of a supplementation fish that escapes to spawn will be a pure natural fish. A supplementation stock can interact with a natural stock in several ways: supplementation and natural fish are jointly removed to provide broodstock for supplementation, they interbreed, supplementation fish can be outplanted as juveniles into a natural population of juveniles, and there may be a joint terminal harvest on both stocks. We assume that supplementation fish, unlike pure hatchery fish, do not return to any hatchery on their own volition.

SUBBASIN ALLOCATION AND HARVEST

As can be seen from Figure A. 1, adults returning to the subbasin are subject to a "hatchery first" policy, in that hatchery broodstock requirements take priority over terminal harvest and spawning escapement. Next, the fish are subject to terminal harvest. For pure hatchery stocks, the terminal harvest rate is generally set to 100 percent in the model -- all pure hatchery subbasin escapement not used for hatchery broodstock is assumed to be harvested in the subbasin. For natural and supplementation stocks, we vary terminal harvest rates from zero to eighty percent, except where the rates are known to be zero. Individuals escaping this terminal harvest are then subject to pre-spawning mortality, and those fish surviving pre-spawning losses are allowed to spawn naturally. This allocation scheme represents a compromise between the complexities of

subbasin-level management and a desire for simplicity in the models, and is not intended to faithfully represent how any particular "real" subbasin is actually managed.

SPAWNING AND SMOLT PRODUCTION

Spawning and smolt production take place either in a hatchery or naturally. For pure hatchery stocks, the process is very straight-forward. Since the only pure hatchery spawners are those taken for broodstock, this broodstock is used to produce a fixed number of smolts (the hatchery smolt capacity), ready to migrate downstream. In order to account for the low survival rates of hatchery smolts relative to naturally produced fish, the smolts are subject to an initial mortality immediately after release, prior to downstream migration. While it may appear overly optimistic to assume that a hatchery will meet its broodstock needs every year, as this method does, currently all model pure hatchery stocks always meet their broodstock requirements. If this assumption proves problematic, we can easily relax it, as is already done for supplementation operations.

For pure natural and supplementation stocks, the situation is a bit more complex. After the spawners arrive on the spawning ground, they are divided into males and females, and we assume that the number of females is the limiting factor in producing viable eggs. Currently, supplementation (hatchery-origin) fish are assumed to have the same characteristics as fish of natural-origin with respect to spawning behavior.

Once naturally spawned eggs hatch out, the number of pre-smolts (now part of the pure natural stock) produced from these eggs is determined based upon one of three density-dependent relationships: the Beverton-Holt (Beverton and Holt, 1957), a logistic survival function (Neter, Wasserman, and Kutner, 1985), or an empirically-derived stock-recruit relationship (Lee and Hyman, 1992).[1] Pre-smolts over-wintering in the subbasin are also subject to an in-basin **mortality each winter they remain in the subbasin; the proportions of pre-smolts staying over for**

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[1] Although the model can incorporate all of the three density-dependent relationships, we used the Beverton-Holt relationship in all model runs.

one, two, or three winters are usually taken from data in the subbasin plans. Once the fish mature to the smolt stage, they are ready to migrate downstream.

Smolt production for supplementation stocks is similar to that for pure hatchery stocks, except for three differences. First, the model allows for the possibility that a supplementation program may not meet its broodstock requirement; if it falls short the smolt output is reduced proportionately. Second, the model allows for the possibility that juveniles are released from the hatchery at a stage where they compete with natural juveniles for food or space, decreasing the survival of both types of juveniles, although this option is not used for any stocks presently included in the analysis. Third, supplementation fish, unlike pure hatchery fish, can be released as pre-smolts, and are thus subject to the same over-wintering mortality as natural pre-smolts.

DOWNSTREAM PASSAGE

Once smolts leave the subbasin, they are subject to downstream mortality. This is calculated in the downstream passage section. While computation of the actual survival proportions is complex (see Chapter 3 and Hinrichsen *et al.* [19911 for more details) the application of the proportions is straight-forward. Separate survival proportions are calculated for hatchery and natural fish, expressed as the proportion of fish surviving from the smolts' entry into the mainstem Columbia or Snake to below Bonneville Dam; these proportions are applied to the number of smolts leaving the subbasin to yield the number of smolts surviving to below Bonneville Dam. These downstream survivals may differ due to different release dates or other factors.

OCEAN SURVIVAL AND NON-TERMINAL HARVEST

Like the Stochastic Life Cycle Model, the deterministic model handles this stage of the life cycle rather differently than the NPPC's System Planning Model (Northwest Power Planning Council, 1989) and other life cycle models, in that it does not make any assumptions about when mortality occurs. The ocean survival and non-terminal harvest relationships are based upon

coded-wire tag (CWT) data. As with any mark-recapture data, CWT data do not contain any direct information on when and where fish die; one can only say when (that is, at what age) and where the fish are recaptured. From the CWT data, one can estimate model parameters which allocate surviving adults to ocean harvest, river harvest, and subbasin escapement, for each age. These parameters are expressed as the proportions of **recovered** fish that ocean harvest, river harvest, and subbasin escapement separately account for. The set of three coefficients for each stock thus provides the likelihood of being recovered in the ocean fishery, the in-river fishery, or of escaping to the subbasin, given that a fish is recovered in any of these three locations.

The proportion of fish that survive to be recovered **(i.e.,** the proportion of smolts reaching below Bonneville dam that survive the estuary and the ocean life stages so that they can be recovered) is then calculated. This single parameter (for each stock) is estimated by making an initial guess and then adjusting its value until the equilibrium subbasin escapement output from the DLCM matches the average observed subbasin **escapement.**[2] The final, stock-specific estimates that yield modeled subbasin escapement that match the observed subbasin escapement become the calibration coefficients for the DLCM. These calibration coefficients are meant to represent the proportion of fish surviving from below Bonneville Dam to recovery in one of the possible locations for recovery **(i.e.,** recovery as ocean harvest, in-river harvest, and subbasin escapement). The value of the estimated calibration coefficients in relation to generally accepted, ballpark values for survival and recovery provides insight into the soundness of the model as a whole.

DETERMINISTIC SIMULATION EQUATIONS

The equations used in the simulation are derived directly from the Stochastic Life Cycle Model. There are three differences between the two models. First, in the Stochastic Life Cycle Model, the transition from one life stage to another is treated as a stochastic process with a probability of transition, P. The deterministic model treats the transitions as fixed proportions,

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[2]**The** average observed subbasin escapement for each stock is calculated from 5 to 20 years of observations on subbasin escapement, depending on data availability.

where the proportions are equivalent to the expected P values within the SLCM. Second, the Stochastic Life Cycle Model utilizes an age-structured population of adult fish (for harvest and spawners); the deterministic model collapses this into an adult population with no age structure. Finally, the Stochastic Life Cycle Model does not produce a non-zero equilibrium population; instead populations vary continuously over time. In contrast, the deterministic model guarantees an equilibrium (of size zero or otherwise).

In the discussion that follows, we describe the model equations in detail. The order is the same as that of the preceding sections of this appendix; variables are defined in Table A. 1. The emphasis in the discussion is on presenting the concepts and principles which serve as the foundation for the model, rather than as a users' guide to the programs. The programs themselves are available from the authors at RFF, and interested parties are urged to contact us for the programs and further information.

One final note before proceeding to the equations themselves. Although it is possible to solve these models analytically, we have opted for a simulation approach. Analytical approaches, involving Leslie matrices and similar techniques produce only modest savings in computer time, and more importantly, are both more complex, in terms of model equations and computer code, and far less flexible than simulation, which can readily incorporate special cases, such as supplementation with several stocks as broodstock sources and/or multiple outplanting locations. Therefore, when reviewing the equations in the sections which follow, keep in mind that these are, in effect, in a larger "DO loop" which runs until the population reaches an equilibrium.

Subbasin Allocation and Harvest

The pure hatchery stock is the most straight-forward case:

HA'ITERHA = HATSUBES - HATREM

where

HATTERHA = Pure Hatchery stock terminal harvest

HATSUBES = Pure Hatchery stock subbasin escapement

HATREM = Pure hatchery stock hatchery brood take.

Thus, for the pure hatchery stock, all not used for broodstock are assumed to be harvested in the subbasin.

For pure natural and supplementation stocks, things are slightly more complex, since the terminal harvest rate is allowed to vary, and the fish are subject to pre-spawning mortality:

NATTERHA = NATSUBES * THRATE

NATSPAWN = (NATSUBES - NATIERHA) * PRSPSV

where

NATTERHA = Natural stock terminal harvest

NATSUEBES = Natural stock subbasin escapement

THRATE = Natural stock terminal harvest rate (varied from 0 to 80 percent in 20
                percent increments)

NATSPAWN = Natural spawners

PRSPSV = Natural stock pre-spawning mortality.

Supplementation is more complex than either of these, and there are several special cases (e.g., Lyons Ferry and Wells hatcheries) which involve multiple broodstock sources and/or outplanting locations.

Spawning and Smolt Production

As might be expected, pure hatchery smolt production is straight-forward. It essentially consists of "pumping out" smolts, as follows:

HSMOLTS = HATCAP * HINTSV

where

HSMOLTS = hatchery smolts

HATCAP = hatchery smolt capacity

HINTSV = Hatchery smolt initial survival rate

As noted earlier, this relationship assumes that pure hatchery stocks always have sufficient broodstock to meet their smolt capacity. In effect, this implies that if a particular hatchery does not have enough fish returning in a given year, it will use broodstock or eggs from another hatchery. In any event, model runs to date suggest that this is not a problem for the hatcheries as modeled.

For natural spawners, there are three functional forms for the egg-to-smolt relationship. The first is the logistic, which works as follows:

FSPAWN = NATSPAWN * MATSPN * FFEM

EGGS   = FSPAWN * EGFEM

P   = LOGITSCl * EXP (LOGITBO + LOGITBl * EGGS) /

        [1 + EXP (LOGITBO + LOGITB 1 * EGGS)]

PRSMT   = EGGS * P

NSMOLTS = PRSMT * INBSMSV

where

FSPAWN = Female spawners

NATSPAWN = Total natural spawners, as defined in the preceding section

MATSPN   = Sexually mature proportion of total spawning escapement

      (To account for jacks among steelhead escapement)

FFEM   = Fraction of spawning escapement that is female

EGFEM   = Eggs per female spawner

P   = Proportion of eggs which survive to become pre-smolts

LOGITSC 1 = Logistic equation scaling parameter

LOGITBO = Logistic equation low-density survival parameter

LGITB1 = Logistic equation high-density survival parameter

PRSMT   = Number of natural pre-smolts produced

NSMOLTS = Naturally spawned smolts leaving the subbasin

INBSMSV = Proportion of pre-smolts surviving to leave the subbasin

             (Set to 1 for smolts leaving as sub-yearlings, < 1 otherwise)

The foregoing equations require some explanation. The expressions for FSPAWN, EGGS, PRSMT and NSMOLTS are straight-forward representations of linear mortality processes. "P", on the other hand, is rather more complex. It is a representation of a survival process in which the likelihood of survival depends on the population density, measured here in terms of number of eggs. LOGITB 1 has more influence on the "P" function's behavior at high densities, while LOGITBO is more influential at lower densities. LOGlTSCl is a density-independent scalar; its effect, like those of the other parameters in the spawning section, is strictly linear. In addition to these equations, we also make allowance for steelhead, which often remain in a subbasin for more than one year. This is done by breaking PRSMT into up to three segments, representing the proportions of smolts leaving as one, two, and three year-olds, and applying INBSMSV to each age class. The equations are omitted from this discussion for compactness.

    For the Beverton-Holt option (which is actually used for all of the stocks in the system-wide cost-effectiveness analysis), the equations are the same as those shown above, except for the "P" function, which is:

$$P = BHINCP / [1 + (BHINCP * EGGS) / BHCAP]$$

where

BHINCP = Beverton-Holt low-density parameter

BHCAP = Beverton-Holt smolt capacity

with other terms as previously defined. This functional form is widely used in fisheries modeling (Beverton and Holt, 1957), and so we do not discuss it further.

The third option for the stock-recruitment relationship is the "empirical" stock-recruitment function. The method used in the Stochastic Life Cycle Model is documented in Lee and Hyman (1992). Because we did not use it in the above-Bonneville analysis, we do not discuss it further.

For supplemented stocks whose members sometimes spawn naturally, the stock-recruit functions are as described above. Note that for supplementation stocks spawning in hatcheries, we allow for the possibility that a supplementation hatchery may not meet its broodstock requirements.

Downstream Passage

The downstream passage portion of the simulation takes smolts produced in the subbasins and transports them to below Bonneville Dam, accounting for mortality incurred along the way. The equations are shown below.

HSMTOSEA = HSMOLTS * HMSURV

NSMTOSEA = NSMOLTS * NMSURV

where

HSMTOSEA = Hatchery-origin smolts below Bonneville Dam

HMSURV = Hatchery-smolt downstream survival, from subbasin of origin
to below Bonneville Dam

NSMTOSEA = Natural-origin smolts below Bonneville Dam

NMSURV = Natural-smolt downstream survival, from subbasin of origin

   to below Bonneville Dam

and HSMOLTS and NSMOLTS are as defined in the "Spawning and Smolt Production"

   section.

ocean survival and Harvest

As noted earlier, this section of the model is constructed somewhat differently from other life-cycle models. The focus is on smolts surviving to adulthood and where the adults are recovered, rather than on survival rates and harvest rates. To see how the recovery factors are calculated, consult the equations below.

OCNRECVRAT = OCNREC/TOTREC

RIVERCVRAT=RIVERC/TOTREC

SUBESCVRAT = SUBREC/TOTREC

where

OCNRECVRAT = Proportion of total recoveries which occur in the

   ocean fishery

RIVRECVRAT = Proportion of total recoveries which occur in the

   m-river fishery

SUBESCVRAT = Proportion of total recoveries which occur in the

   subbasin (as subbasin harvest or returns to the hatchery

   or natural spawning area).

Recoveries are based upon analysis of coded-wire-tag (CWT) data. Because CWT data is rarely available for naturally spawned fish, we usually employ the same parameters for both hatchery, natural, and supplementation stocks. One exception to this rule is for naturally

produced steelhead, which we assume are not subject to non-terminal harvest. Note that although this approach avoids assumptions about mortality rates, it also means that changes in non-terminal harvest rates (as management actions to benefit the fish) must be handled carefully to avoid other problems. Since we do not include changes in non-terminal harvest regimes in the current version of the model, this type of calculation is not shown here.

The next step is to calculate the actual numbers of fish, by stock, which are recovered. To do this, we employ a fitting parameter for each stock, which is designed so that average subbasin escapement for the calibration case (see Chapter 4) is the same as the historical record for each stock. The equations for hatchery and natural stocks are shown below.

$$HOCNHARV = HSMTOSEA * OCNRECVRAT * HADTRECV$$

$$HRIVHARV = HSMTOSEA * RIVRECVRAT * HADTRECV$$

$$HATSUBES = HSMTOSEA * SUBESCVRAT * HADTRECV$$

$$NOCNHARV = NSMTOSEA * OCNRECVRAT * NADTRECV$$

$$NRIVHARV = NSMTOSEA * RIVRECVRAT * NADTRECV$$

$$NATSUBES = NSMTOSEA * SUBESCVRAT * NADTRECV$$

where

HOCNHARV = Hatchery-stock ocean harvest

HRIVHARV = Hatchery-stock in-river harvest

HATSUBES = Hatchery-stock subbasin escapement

HADTRECV = Hatchery-stock fitting parameter, expressed as adults per

               smolt arriving below Bonneville Dam

NOCNHARV = Natural-stock ocean harvest

NRIVHARV = Natural-stock in-river harvest

NATSUBES = Natural-stock subbasin escapement

NADTRECV = Natural-stock fitting parameter, expressed as adults per

smolt arriving below Bonneville Dam

MODEL OUTPUTS

The outputs from the deterministic simulation serve as inputs to the optimization model. Recall that the simulation model is run once per stock/propagation strategy/passage strategy combination. The simulation model population projections on runsize, terminal harvest and spawning escapement are then used by the optimization model, to calculate basin-wide cost-effective strategies to meet goals for harvest and spawning escapement. At present, both models concentrate on subbasin harvest, but this could be expanded to include non-terminal harvest, if required.
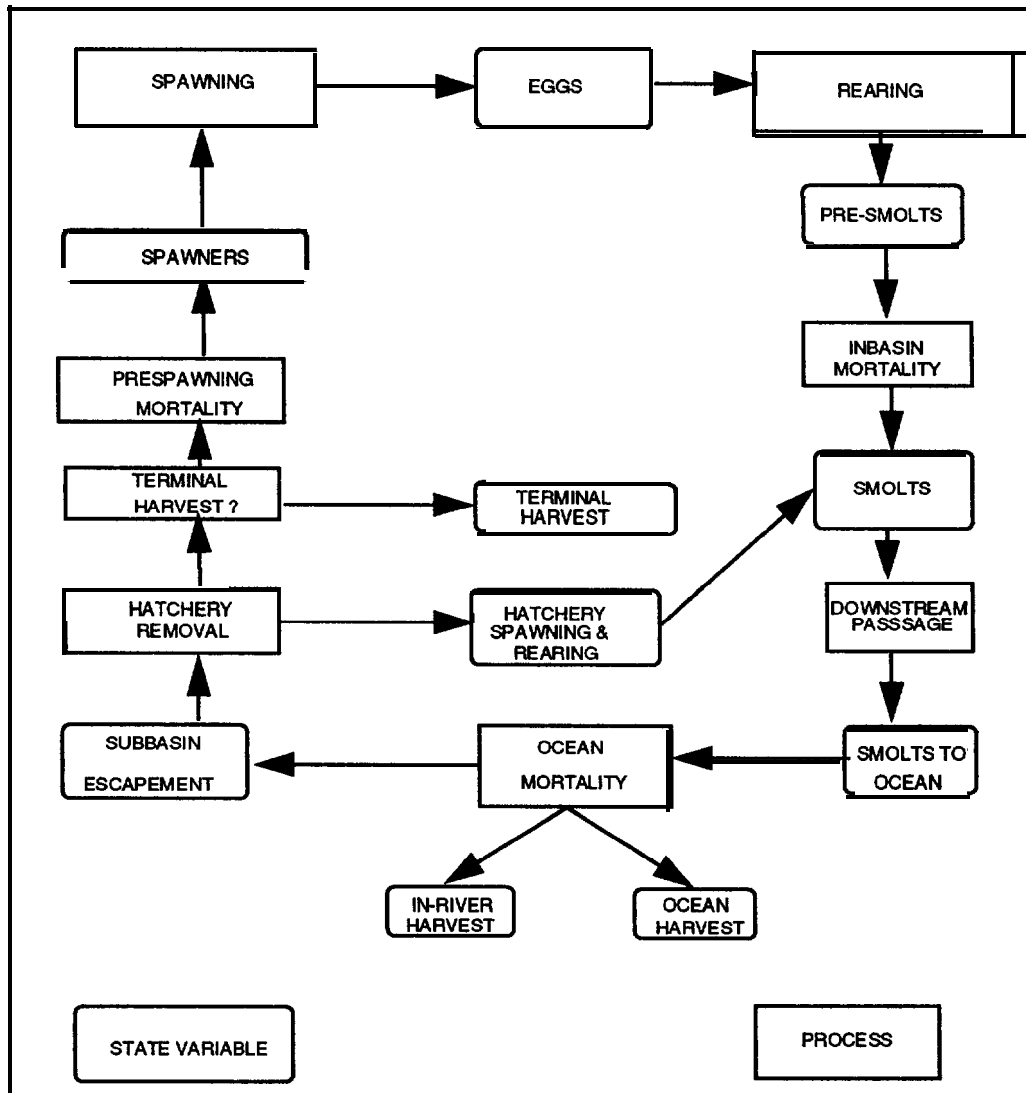
FIGURE A.1. SALMON LIFE CYCLE

HATCHING OF EGGS

SPAWNING OF ADULTS

| HATCHERY | PURE HATCHERY STOCK | HATCHERY |

SUPPLEMENTATION STOCK

| STREAM | PURE NATURAL STOCK | STREAM |
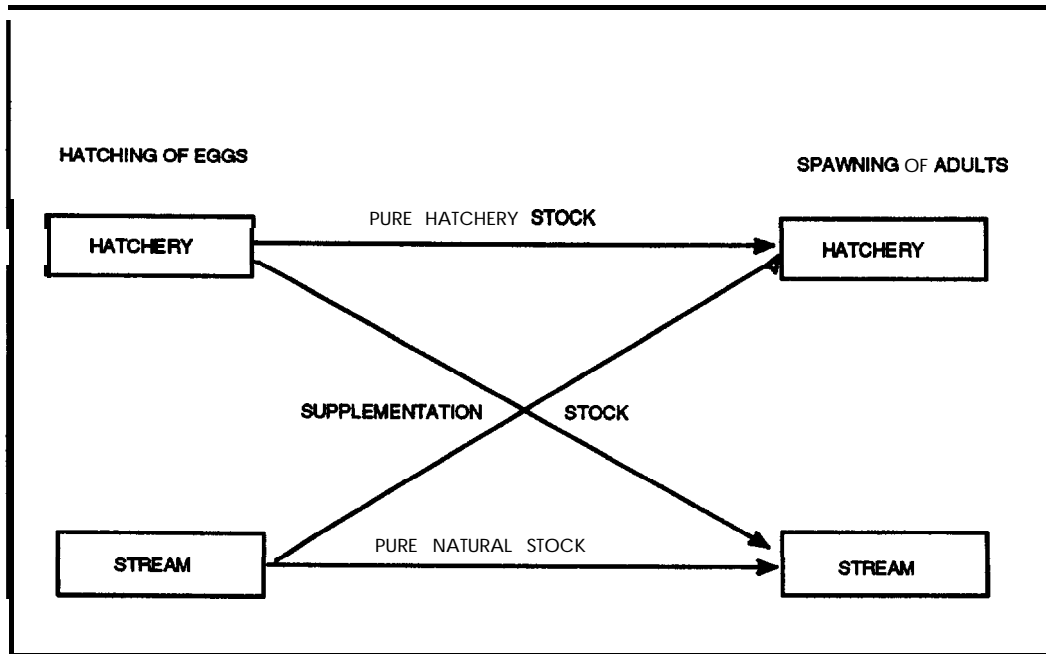
Figure A.2. Illustrated Definition Of Pun, Hatchery, Supplementation, and Natural Stocks

TABLE A.1
Deterministic Simulation Model Variables and Definitions

Variable*	Definition
HATTERHA	Pure Hatchery stock terminal harvest
HATSUBES	Pure Hatchery stock subbasin escapement
HATREM	Pure hatchery stock hatchery brood take.
NATTERHA	Natural stock terminal harvest
NATSUBES	Natural stock subbasin escapement
THRATE	Natural stock terminal harvest rate
NATSPAWN	Natural spawners
PRSPSV	Natural stock pre-spawning mortality.
HSMOLTS	hatchery smolts
HATCAP	hatchery smolt capacity
HINTSV	Hatchery smolt initial survival rate
FSPAWN	Female spawners
NATSPAWN	Total natural spawners
MATSPN	Sexually mature proportion of total spawning escapement (to account for jacks among steelhead escapement)
FFEM	Fraction of spawning escapement that is female
EGFEM	Eggs per female spawner
P	Proportion of eggs which survive to become pre-smolts
LOGITSCl	Logistic equation scaling parameter
LOGITBO	Logistic equation low-density survival parameter
LOGITBl	Logistic equation high-density survival parameter
PRSMT	Number of natural pre-smolts produced
NSMOLTS	Naturally spawned smolts leaving the subbasin
INBSMSV	Proportion of pre-smolts leaving the subbasin. Set to 1 for smolts leaving as sub-yearlings, 0 otherwise
BHINCP	Beverton-Holt low-density parameter
BHCAP	Beverton-Holt smolt capacity
HSMTOSEA	Hatchery-origin smolts below Bonneville Dam
HMSURV	Hatchery-smolt downstream survival, from subbasin of origin to below Bonneville Dam
NSMTOSEA	Natural-origin smolts below Bonneville Dam
NMSURV	Natural-smolt downstream survival, from subbasin of origin to below Bonneville Dam
OCNRECVRAT	Proportion of total recoveries which occur in the ocean fishery
RIVRECVRAT	Proportion of total recoveries which occur in the in-river fishery
SUBESCVRAT	Proportion of total recoveries which occur in the subbasin
HOCNHARV	Hatchery-stock ocean harvest
HRIVHARV	Hatchery-stock in-river harvest
HATSUBES	Hatchery-stock subbasin escapement
NOCNHARV	Natural-stock ocean harvest
NRIVHARV	Natural-stock in-river harvest
NATSUBES	Natural-stock subbasin escapement
NADTRECV	Natural-stock fitting parameter, expressed as adults per smolt arriving below Bonneville Dam
HADTRECV	Hatchery-stock fitting parameter, expressed as adults per smolt arriving below Bonneville Dam

*   Bolded variables are exogenous, fixed parameters, while variables without bolded text are variables whose values are calculated endogenously.

APPENDIX B
OPTIMIZATION MODEL DESCRIPTION

INTRODUCTION

The optimization model identifies the least-cost combination of passage, propagation, and harvest alternatives to meet a set of numerical goals for each stock. In this appendix, we begin with a brief review of concepts presented in Chapter 2, including system complexity and management strategies. We then proceed to a siinpllfied example of the workings of the optimization model. We develop the example heuristically, to give an intuitive feel for how the optimization model solves the system-wide C/E problem. Next, we lay out the equations which formally comprise the model structure as applied to the above-Bonneville subbasins in this report. In the next-to-last section, we combine the heuristic example with the formal optimization equations, and describe the example using the notation developed for the formal description. The appendix concludes with our thoughts on how the optimization model could be extended to handle more complex objectives, including dynamic analyses and explicit consideration of stochasticity.

SYSTEM COMPLEXITY

The area above Bonneville Dam contains steelhead, sockeye salmon, and several runs (spring, summer and fall) of chinook salmon, and other fish as well. We have excluded sockeye from our analysis, due to the lack of biological data and stock-specific objectives for most sockeye populations. The subbasin planners divide each species into stocks, based upon the subbasin where they spawn and whether they are of hatchery or natural origin. We make an additional division of hatchery-origin fish into "pure" hatchery and supplementation stocks. The result is that we analyze management objectives and management actions for 79 stocks.

In addition to the large number of stocks, two other factors complicate the analysis. First, as noted earlier, passage actions affect more than one stock at a time. Actions specific to a particular dam affect every stock above that dam, while flow actions affect all stocks migrating

during the period when the flow action is in operation. Second, even within subbasins, propagation actions often affect every stock which spawns in the subbasin. Finally, the number of adults procuced is a function of both propagation and passage conditions. The result is that one cannot hope to find a system-wide combination of passage and propagation actions to meet the stock-specific objectives at least cost without taking account of these interactions. The reader may wish to refer to the simple example in Chapter 2; definitions of key terms are repeated in Table B.l.

EXAMPLE PROBLEM

To help provide a better understanding of the workings of the optimization, we have created a small empirical example using data from one of the scenarios reported in Chapter 5. For the example, we have chosen two subbasins -- the Clear-water and the Deschutes -- and two stocks for each of the subbasins -- spring chinook and summer steelhead. Each subbasin has two propagation strategies: a base case and a strategy with improved habitat. Each stock in each subbasin has two terminal harvest rates: twenty and forty percent. In addition, the two-subbasin system has two passage strategies: a base case and strategy with improved downstream passage. We show these alternatives in Table B.2.

Following the logic in Chapter 2, there are 16 propagation/terminal harvest/passage alternatives for each subbasin (2 propagation strategies * 2 passage strategies * 2 stocks * 2 terminal harvest rates per stock). This, in turn, leads to 128 possible system-wide strategies, looking across all of the combinations of system-wide passage strategies, subbasin-specific propagation strategies, and stock-specific terminal harvest rates (*i.e.,* 2 passage strategies * [2 Clearwater propagation strategies * 2 Clearwater stocks * 2 terminal harvest rates per stock] * [2 Deschutes propagation strategies * 2 Deschutes stocks * 2 terminal harvest rates per stock]).

Having determined which alternatives are of interest, the next step in the process is to use the deterministic life cycle model to calculate terminal harvest and spawning escapement levels for each alternative for each stock. Table B.3 shows the numerical results from the deterministic

simulation model for each of the propagation-terminal harvest-passage alternatives (16 for each of the two subbasins). Table B.4 shows which alternatives meet the goals for each **stock**[1].

We will now try to demonstrate how the basin-wide model identifies the least-cost system-wide strategy to meet the objectives for each stock.[2] The first step is to select the propagation-terminal harvest-passage alternatives that meet the goals for both stocks, since alternatives which do not meet the objectives can be excluded from further consideration. Starting with the results shown in Table B.4, one can see that within each subbasin, only a small subset of the alternatives meet the terminal harvest and spawning goals for both stocks simultaneously. Looking only at these **feasible** alternatives limits the number of possibilities considerably; we show the feasible alternatives in Table B.5. This reduces the number of alternatives under consideration from 32 to 15. Furthermore, because base case passage and base-case propagation do not meet the objectives for Cleat-water spring chinook, we can eliminate all alternatives in Table B.5 that contain either the base-case passage strategy, the Cleat-water base case propagation strategy, or both. Eliminating base-case passage and Cleat-water base case propagation is possible since both subbasins must use the same passage strategy *(i.e.,* improved passage), and within the Clearwater, both steelhead and chinook must use the same propagation strategy *(i.e.,* improved habitat). This leaves 8 propagation-terminal harvest-passage alternatives still under consideration; they are shown in Table B.6.

At this point, we are left with only one combination of passage and propagation for the Clearwater: improved passage conditions and improved habitat. In addition, we can see from Table B.6 that no choices remain on harvest rates for the Clearwater -- only the forty percent terminal harvest rates are still under consideration, since the twenty percent rate does not meet the

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[1]The choice of goals (i.e., terminal harvest and spawning escapement) are similar to those chosen by the subbasin planners. We have modified the planners' specific numerical objectives for this example to provide a better illustration of how the optimization model works.

[2]The intention behind this example is to show how the model solves the optimization problem based on ordinary intuition. Technically, the model uses a modified simplex method, which gives the same result using different computational methods than those presented here.

terminal harvest objectives. For the Deschutes, things are slightly more complicated. (Recall that Deschutes alternatives using base case passage were eliminated above.) At this point (and not before) costs enter into the picture. First of all, it is obvious that doing nothing costs less than habitat improvements, and since base-case propagation conditions still allow the Deschutes harvest and spawning escapement goals to be met, we can eliminate habitat improvement strategies from further consideration in the Deschutes. This leaves only the twenty percent harvest rate alternatives for spring chinook and steelhead in the Deschutes, since the alternatives using forty percent terminal harvest do not meet spawning escapement objectives for either stock. Table B.7 , then, shows the system-wide cost-effective strategy. The strategy consists of passage improvements, habitat improvements in the Clearwater, and base case propagation conditions in the Deschutes.

To summarize the screening process, the procedure for finding the system-wide least-cost strategy which meets the objectives for all stocks consists of the following steps:

1. Run the deterministic simulation mode: (described in appendix A) for each passage/propagation/terminal harvest alternative, for each stock.

2. For each stock, find and eliminate all passage/propagation/terminal harvest alternatives that are infeasible *(i.e.,* alternatives that do not meet the stock's terminal harvest and/or spawning goals).

3. Determine which passage strategy is common among all alternatives remaining under consideration, and eliminate any alternatives chosen in (2) which use a different passage strategy.

4. For each subbasin, select the lowest-cost propagation strategy from those remaining after step (3)

5. For each passage/propagation/terminal harvest alternative remaining after step (4), select a terminal harvest rate. The result will be the system-wide cost-effective strategy.

Obviously, as the system under consideration becomes more complex, this simple solution procedure would need to be expanded. For example, more than one passage strategy may meet

the goals for all stocks (in combination with propagation strategies in each subbasin). In addition, it is possible that no passage/propagation/terminal harvest alternative will meet the objectives for some stocks. Finally, some stocks may be able to meet their goals using more than one terminal harvest rate. The next section shows how the simple methods explained above can be extended to the more complex above-Bonneville analysis.

OVERVIEW OF MODEL STRUCTURE

This section explains the structure of the optimization model in detail. In contrast to the heuristic description, in this section we present and explain the equations in the actual optimization. We demonstrate how the model is constructed and the logic behind each of the equations, but we do not explain how the model actually solves the linear programming problem. In the section following this one, we have an example of how to construct the matrix of equations used by the model, using the same data as the heuristic example.

In reading the subsections which follow, several points should be kept in mind. First, the model structure is explained sequentially, as though the optimization looked at costs first, passage strategies second, and so forth. We do this solely for ease in explication. In fact, the algorithm which is employed (a modified simplex[3]) looks at the biological objectives, passage and propagation strategies, costs, and other information simultaneously to identify a system-wide least-cost strategy. Second, the model structure is complicated because it contains so many subbasins and stocks. However, the crux of the problem is really fairly simple. The objective of the exercise is to select the combination of passage, propagation, and terminal harvest options which will meet a set of stock-specific goals, and do so at least cost. Third, with the exception of the **objective function** (which has cost information for each passage and propagation strategy), and **constraints** on fish production (to ensure that the model "produces" at least as many fish of

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[3]The model is solved using SAS PROC LP (SAS is a registered trademark of the SAS Institute, Cary, NC). PROC LP uses a modified version of the simplex algorithm, and for this model, requires approximately one to three hours of CPU time to solve the basin-wide linear programming (LP) parts of the model.

each stock as the user specifies) the model structure is made up of what are known in optimization *as mass-balance constraints. These* serve to ensure that the solution is internally consistent, such that the Deschutes subbasin, for example, uses the same downstream passage strategy as the Clearwater, and that Clearwater chinook and steelhead both use the same propagation strategy.

In the context of the system-wide model, the essential concepts can be explained without reference to the technical details, which are described in subsequent sections of this appendix.4 The task of the optimization model is to meet stock-specific goals for terminal harvest and spawning escapement at the lowest possible system-wide cost, given the available passage strategies, propagation strategies, and terminal harvest rates. Using the terms defmed in Chapter 2, the linear program (LP) must choose a single system-wide least-cost strategy, using a combination of one passage strategy (for the entire basin) and one propagation strategy per subbasin, and one terminal harvest rate per stock.

In the remainder of this section, we first define the variables used in the optimization model, then define the equations used for the passage, propagation, fish production, and constraint portions of the optimization. Readers unfamiliar with optimization models in general and linear programming terms in particular may wish to consult Table B.8 for some informal definitions of the technical terms used in the discussion. Table B.9 shows the definitions of the variables and subscripts used in the discussion below.

Recall from the earlier discussion that only passage and propagation strategies have costs. Therefore, they are the only LP activities which have objective function entries:

---

[4]In traditional matrix notation, the formal structure of the linear programming model is

Minimize   c x

Subject to $\mathbf{AX=B}$

where "X" is an array of decision variables, "C" is an array of costs, **"A" is** a matrix of technical coefficients, and "B" an array of constraints.

$$\text{Minimize} \sum_m (PASS_{,,} * CPASS_) + \sum_i \sum_r (PROP_{,,} * CPROP_{i,n}) \tag{1}$$

where:

$PASS_m =$ Passage strategy

$PROP_{i,n} =$ Propagation strategy

$CPASS_m =$ Cost of passage strategy

$CPROP_{i,n} =$ Cost of propagation strategy (cost of strategy is

                   sum of costs of actions included in strategy).

As the LP chooses among combinations passage and propagation strategies, the values for $PASS_m$ and $PROP_{i,n}$ take on non-zero values.[5] The LP will minimize the total cost of passage and propagation, while at the same time it meets constraints on fish production and the internal mass-balance constraints described below. Note that the set of system-wide passage strategies, and each set of subbasin-specific propagation strategies, will include one base-case strategy with cost of 0.

Next, since the LP can use only one system-wide downstream passage strategy,

$$\sum_m PASS_{,,} = 1 \tag{2}$$

Equation (2) requires the LP to choose exactly one system-wide passage strategy, since the $PASS_m$ variables can only take on $0/1$ values.

The next set of equations are mass-balance constraints used to ensure that the subbasin

---

[5]In practice, all model activities (passage, propagation, etc.) take on only two values -- zero or one -- in the system-wide cost-effective strategy.

and stock-level passage capacities can operate only if the required system-wide passage strategy activity has taken on a value of **one**[6].

$$\forall_{i} \ SUBPASS_{i,m} = PASS,,, \tag{3}$$

$$\forall_{j} \ STOCKPASS_{i,j,m} = SUBPASS_{i,m} \tag{4}$$

where:

$SUBPASS_{i,m} =$ Subbasin -specific passage activities

$STOCKPASS_{i,j,m} =$ Stock-specific passage activities.

Equations (3) and (4) connect the $PASS_{m}$ activities to subbasins and stocks in the following fashion. Suppose that the **LP** operates PASS2 which then takes a value of 1. Then $SUBPASS_{i,2}$ will need to take on a value of 1 (to meet the constraint in equation **(3)**), as will $STOCKPASS_{i,j,2}$, in order to fulfii the requirements of equation (4). This will hold for all subbasins (i.e., for every "i") and for all stocks in each subbasin (i.e., for every **"j").** In other words, one $PASS_{m}$ must be equal to one in order to operate the corresponding $SUBPASS_{i,m}$ variable. A $SUBPASS_{i,m}$ variable must equal one in order to operate $STOCKPASS_{i,j,m}$, and, in turn, one $STOCKPASS_{i,j,m}$ variable must be greater than zero to "operate" the corresponding stock-specific alternative, in the adult production section. This ensures that a given system-wide passage strategy will be linked correctly to the subbasin and stock-level passage activities. The STOCKPASS capacities are used to "create" fish, as described below.

The propagation capacities are constructed in much the same fashion as the passage capacities. The first are the subbasin-level propagation strategies.

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[6]**The** symbol $\forall_{i}$ denotes "for every i".

$$\forall_i \sum_n PROP,, = 1 \tag{5}$$

where the $PROP_{i,n}$ are as previously defined in equation (1). There are "I" constraints on propagation strategies or activities, one per subbasin. This set of constraints ensures that exactly one propagation strategy will be chosen for each subbasin, in the same way that equation (2) ensures that exactly one passage strategy will be chosen system-wide. It also ensures that when a propagation strategy *is* chosen, the corresponding $PROP_{i,n}$ variable will then take a value of exactly one.

As with the passage strategies, the propagation strategies are split into stock-specific capacities.

$$\forall_j STOCKPROP_{i,j,n} = PROP_{i,n} \tag{6}$$

where:

$STOCKPROP_{i,j,n} =$ Stock-level propagation activities.

This set of constraints ensures that the stock-level STOCKPROP activities can take on a value of one if and only if the corresponding subbasin-level PROP activities are non-zero. For example, $STOCKPROP_{1,2,3}$ can be equal to one if and only if $PROP_{1,3} = 1$. The STOCKPROP variables are used in the adult production section, below.

The adult production activities use the stock-specific capacities created in the previous two sections. The result, is that any given adult production activity, $MAKEFISH_{i,j,m,n,h}$, can only operate, (i.e., take on a value of one) if its corresponding passage and propagation strategies also are equal to one.[7]

---

[7] Note that the model will contain a $MAKEFISH_{i,j,m,n,h}$ for every passage/propagation/terminal harvest alternative, for every stock. These are the activities or decision variables which actually "produce" fish.

$$\forall_{i,j,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h} = \text{STOCKPASS}_{i,j,n} \tag{7}$$

and

$$\forall_{i,j,m} \sum_h \text{MAKEFISH}_{i,j,m,n,h} = \text{STOCKPROP}_{i,j,m} \tag{8}$$

where $\text{MAKEFISH}_{i,j,m,n,h}$ = fish production activity, harvest rate h.

In effect, equations (7) and (8), in combination with equations (3), (4), and (6), ensure that any given propagation/terminal harvest/passage alternative, $\text{MAKEFISH}_{i,j,m,n,h}$, can take a value of one in the model solution only if the corresponding system-wide passage strategy and subbasin-level propagation strategy are operated by the LP. The summations are needed so that all harvest rates will sum to one, and exactly one terminal harvest rate will be operated for each stock.

The final portion of the LP determines whether or not each MAKEFISH activity meets objectives for terminal harvest and spawning escapement for each stock. This uses the data produced by the deterministic simulation model (described in Appendix A) on the number of adults harvested in the subbasin and the number escaping to spawn.

$$\text{SPAWGOAL}_{i,j} = \forall_{m,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h} \cdot b_{i,j,m,n,h} \tag{9}$$

$$\text{HARVGOAL}_{i,j} = \forall_{m,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h} \cdot a_{i,j,m,n,h} \tag{10}$$

where:

$\text{HARVGOAL}_{i,j}$ =   1 if a non-zero harvest goal has been established for stock i,j; 0 otherwise;

$\text{SPAWGOAL}_{i,j}$ =   1 if a non-zero spawning escapement goal has been established for

stock i,j; 0 otherwise;

$a_{i,j,m,n,h}$ $\quad$ = $\quad$ 1 if MAKEFISHi,j,m,n,h meets or exceeds the harvest objective for stock i,j; 0 otherwise (based on output from the DLCM)

$b_{i,j,m,n,h}$ $\quad$ = $\quad$ 1 if MAKEFISH$_{i,j,m,n,h}$ meets or exceeds the spawning escapement objective for stock i,j; 0 otherwise (based on output from the DLCM)

MAKEFISH$_{i,j,m,n,h}$ as previously defined.

Equations (9) and (10) are where the rubber finally meets the road, in that these let the LP know which **MAKEFISH** alternatives actually meet the goals for each stock. If a particular MAKEFISH$_{i,j,m,n,h}$ meets or exceeds the stocks terminal harvest goal (based on calculations in the Deterministic Life Cycle Model) its $a_{i,j,m,n,h}$ is set to 1, otherwise the $a_{i,j,m,n,h}$ is set to zero (and similarly for the $b_{i,j,m,n,h}$ and spawning escapement). In this way, the LP determines whether or not each MAKEFISH$_{i,j,m,n,h}$ is a potential part of a feasible solution (i.e., one which meets the goals for all stocks). Once the LP has found the feasible subset of MAKEFISH$_{i,j,m,n,h}$'s, it then checks to see which combination of passage and propagation strategies the feasible set of MAKEFISH$_{i,j,m,n,h}$'s have in common. This set of common passage and propagation alternatives is then checked to see which passage/propagation combination has the lowest cost, producing the system-wide least-cost strategy for a given set of adult production goals.

HEURISTIC OPTIMIZATION EXAMPLE

In this section we combine the heuristic example and the optimization equations developed earlier in this appendix. The result is an LP *tableau* which contains all of the equations **required** to solve the LP for the small heuristic example.

The starting point for this is Table B.4, which shows the results for 32 runs of the Deterministic Simulation Model. This contains all of the biological information required to build

an actual LP for the heuristic model. The only other information needed is the cost of the passage and propagation strategies, shown in Table B. 10.

The LP tableau is shown in Table B. 11. We show how each element in the tableau is constructed. For convenience in exposition, we follow roughly the same order as in the preceding section.

In this discussion, we focus on how one can translate the heuristic example into a form that the linear programming model can solve. Before plunging into the details of the translation, however, some background on how to interpret the admittedly imposing tableau may be useful. In Table B. 11, the rows of the Table represent LP equations, while the columns are LP "decision variables" which the LP can operate at a value of either zero or one. Essentially, the equations are conditions which the LP must meet -- harvest objectives to be achieved, et cetera -- and the columns are activities which the LP can undertake in order to meet them. When the LP solves, or selects a system-wide least-cost strategy, it decides which columns or activities will take on a value of one, and which will take on a value of zero, while meeting the constraints shown in the rows of the tableau.. In the tableau, columns D and E represent passage strategies, while F through I represent propagation strategies. Columns J through M link strategies to alternatives, while N through AS represent passage/propagation/terminal harvest alternatives.

Each equation or row in the tableau can be interpreted as the sum of the columns or activities values in the solution multiplied by the coefficients in the body of the table (since the matrix of coefficients is very sparse, most zero values are left blank in the tableau). For example, row three in the tableau is interpreted as follows:

$$\text{PASS-SOS-ROW} = 1 \text{ (since it has a right-hand-side of 1).} \tag{11}$$

$$\text{PASS-SOS-ROW} = (\text{PASS-BASE} * 1) + (\text{IMPRPASS} * 1) \tag{12}$$

Equation (11) means that for the LP to solve the problem, PASS-SOS-ROW must be equal to 1. Equation (12) means that sum of the PASS-BASE and IMPRPASS activities must equal 1, or in

other words that exactly one of them must be "operated" by the LP. No other activities are involved in row 3 of the tableau, since all other activities have a coefficient of zero in row 3. With this as background, we now proceed to the details.

Column "A" shows which equation numbers (from the previous section) each row of the tableau refers to. The row name is in column "B", the "right-hand-side" in column "C", and the activity or strategy names in columns "D" through "AS". Row 1 in Table B. 11 contains identifying information for the rows and columns. Row 2 contains the objective function, and has non-zero entries only for the activities with non-zero costs -- the passage activities PASS-BASE and IMPRPASS, and the propagation activities PROP-DE-BASE, PROP-DE-IMPROVED, PROP-CL-BASE, and PROP-CL-IMPROVED. The passage strategies are, respectively, the base case, PASS-BASE, (with a cost of zero) and an improvement, IMPRPASS, which costs $9 million per year. The propagation strategies apply to two subbasins (Deschutes, or "DE", and the Clearwater, "CL") and are their base cases or improvements in propagation represented by "BASE" or "IMPROVED" in the column names. The objective function is the equation which the model tries to minimize. By convention the right-hand-side of the objective function is denoted by an "N" in the RHS column, meaning that the row is unconstrained. (All other rows have a right-hand-size of either 0 or 1.) The interpretation of row 2 of the tableau is that the objective function is:

OBJROW =   (PASS-BASE * 0) + (IMPRPASS * 9) +

(PROP-DE-BASE * 0) + (**PROP_DE_IMPROVED** * 0.3) +

(PROP-CL-BASE * 0) + (PROP-CL-IMPROVED * 0.41)

The LP will minimize the value of this function, subject to the constraints described below. In effect, the model will chose which strategies (columns in the tableau) to set to one, and which to set to zero, so as to meet the constraints and minimize the value of the objective function.

Recall from equations (2) and (5) that the LP can use only one system-wide passage

strategy and one propagation strategy for each subbasin. This is shown in row 3 of Table **B.11** for the passages strategies, and rows 16-17 for the propagation strategies. For passage, the sum of PASS-BASE and PASS-IMP is constrained to be equal to 1 (from row 3's RHS value) so only one of the passage strategies (either the base case or the improvement strategy) will operate. The same applies for the propagation strategies for each subbasin, with row 16 constraining the Deschutes propagation strategies, and row 17 constraining the Clearwater, to be equal to one.

Equations (3) and (4) ensure consistency between the basin-wide passage strategy and the passage strategy used at the subbasin and stock levels. This is translated into the model tableau in rows 4-7 for equation (3), and rows 8-15 for equation (4). For example, row 4 specifies that the values for PASS-BASE (column **"D")** and **SUBPASS_DE_BASE** (column **"J")** must equal each other:

DE-PASS-BASE = 0 (since the RHS of row 4 = 0), and

DE-PASS-BASE = PASS-BASE * 1 + **SUBPASS_DE_BASE** * -1.

This ensures that if the LP operates the base-case passage strategy, PASS-BASE, it must also operate **SUBPASS_DE_BASE,** thus meeting the requirement imposed by equation (3). Conversely, the model cannot operate **SUBPASS_DE_BASE** without also operating PASS-BASE.   Similarly, rows 8 and 9 in the tableau assure that if **SUBPASS_DE_BASE** is operated by the LP, both Deschutes spring chinook **(DE_SPC_BASEPASS_ROW)** and Deschutes summer steelhead (DE,SSH-BASEPASS-ROW) will use the base-case passage strategy, and therefore meet to requirement of equation (4).

A similar set of relationships holds for the propagation activities. Equation (6) requires that each individual stock within a subbasin uses the same propagation strategy. This is made operational in rows 18-25 of the tableau. In row 18, for example, the constraint **DE_SPC_BASEPROP_ROW** assures that both spring chinook and steelhead within the Deschutes will use base-case propagation if and only if the PROP-DE-BASE activity (column

"F" in the tableau) is operating with a value of 1.

Equations (7) through (9) all involve the "MAKEFISH" variables, and are shown in columns N-AS of the tableau. These variables perform four tasks simultaneously:

1. Ensure consistency between the system-wide passage strategy and the passage/propagation/terminal harvest alternative.
2. Ensure consistency between the subbasin-level propagation strategy and the passage/propagation/terminal harvest alternative.
3. Meet the stock-level terminal harvest goal, if possible.
4. Meet the stock-level spawning escapement goal, if possible.

Decoding the names of the variables is fairly straightforward, and follow the naming convention established for the **MAKEFISH** variables in the preceding section. The first eight characters are always "MAKEFISH", as was the case in the equations in the earlier discussion. The next two letters are an abbreviation for the name of the subbasin ("DE" for Deschutes, "CL" for Clearwater). The next three letters are an abbreviation for the species **("SPC"** for spring chinook, "SSH" for summer steelhead). This is followed by a designation for the passage strategy ("BASEPASS" or "IMPRPASS" for base-case or Improved passage, respectively), and propagation strategy ("BASEPROP" or "IMPROP", for base case and Improved propagation, respectively). Finally, a designation for terminal harvest rate completes the activity name **("TH20"** or **"TH40").** Taking column **"Q"** from the tableau as an example, the activity name is **"MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40".** This means that it is a fish production alternative from the Deschutes subbasin for spring chinook. It uses base-case passage, Improved propagation, and a terminal harvest rate of 40 percent.

Obviously, the alternative in column Q of the tableau should only be able to operate, or take on a non-zero value, if the base-case passage strategy and the improved-habitat Deschutes propagation alternative both take on a value of 1. These conditions are met via two of the non-zero coefficients in column Q. First, placing a - 1 in row 8, "DE-SPCBASEPASS-ROW", we ensure that **"MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40"** can operate if and only if

column J, "SUBPASS-DE-BASE", also takes on a value of 1, since **"DE_SPC_BASEPASS_ROW"** must be equal to zero, its right-hand-side (RHS) value. (Recall from model equation (3) that column J, in turn, can be equal to 1 if and only if column D, "PASS-BASE", is also equal to 1.) This of course links column Q back to the **LP's** "choice" of a passage strategy. In a similar fashion, the -1 in column Q, row 20, **"DE_SPC_IMPROP_ROW"**, requires that the passage improvement strategy, column G, "PROP-DE-IMPROVED", operate before column Q can take on a non-zero value, since **"DE_SPC_IMPROP_ROW"** must be equal to zero.

Equations (9) and (10) address whether or not an alternative meets the terminal harvest and subbasin escapement goals for a stock. We see from tables B.3 and B.4 that the passage/propagation/terminal harvest alternative represented by column Q meets both the terminal harvest and spawning escapement goals for Deschutes spring chinook. This is represented in the tableau by the coefficient **"1"** in row 26 (for Deschutes spring chinook terminal harvest goal) and the coefficient **"** 1" in row 30 (for Deschutes spring chinook spawning escapement goal). Whether these coefficients are zero or one is determined by running the DLCM. Obviously, many alternatives will fail to meet one or both goals. For example, in column N (Deschutes base case passage and propagation, 20 percent terminal harvest rate) both rows 26 and 30 have coefficients of zero, so the alternative met neither goal. All of the **MAKEFISH** alternatives in columns N--AS are constructed using the same logic as in the example. As noted previously, there is one MAKEFISH column in the tableau for each passage/propagation/terminal harvest alternative for each subbasin and stock.

POTENTIAL EXTENSIONS

Other Objectives

In Chapter 5, we discuss the use of the optimization model to investigate strategies for doubling the runsize of each stock. We did this by simply substituting constraints on runsize for

those on terminal harvest and spawning escapement, and running the DLCM to produce information on total runsize for each stock. Other stock-specific objectives, including constraints on ocean harvest, in-river harvest, or even smolt production, could easily be added to the model or substituted for the objectives already analyzed.

Variability and Uncertainty

As currently constructed, the cost-effectiveness models do not directly address natural variability in the fish production measures employed. This is a direct outgrowth of the fact that the DLCM is deterministic. There are two reasons we chose a deterministic model to simulate the fish life cycle. The first is that the planners' goals for harvest and escapement are stated in terms of averages over a long time period, as is the NPPC's runsize-doubling goal. The second is that the DLCM must analyze approximately 80,000 passage/propagation/terminal harvest alternatives for the above-Bonneville cost-effectiveness modeling. The DLCM requires about fifteen minutes (900 seconds) to analyze the alternatives, or approximately 0.01 seconds per alternative.

As noted in Appendix A, the DLCM is a deterministic simplification of the Stochastic Life Cycle Model, or SLCM. The SLCM mimics natural variability of salmon populations by treating model parameters as random draws from probability distributions. The SLCM requires approximately five minutes to analyze an alternative, which translates into roughly nine months of computer time to analyze the 80,000 alternatives used to date. This, obviously, explains why we developed the DLCM for the above-Bonneville project. While in principle one could use the SLCM as the biological simulation model and formulate objectives in terms of probability distribution moments (e.g., the 10th percentile of spawning escapement should not fall below x) practical problems preclude extending this to all of the stocks and alternatives analyzed with the DLCM.

Fortunately, the problem is not as severe as it might seem. Data for many stocks is insufficient to calibrate them properly for the SLCM; only about one-quarter of the nearly 80

stocks in the above-Bonneville analysis have sufficiently long time-series of adult returns to calibrate the variance terms in the stochastic model. We expect that it will be feasible to run the SLCM for the management alternatives which apply to these stocks, and substitute moments of probability distributions for the averages used to calculate the $a_{i,j,m,n,h}$'s and $b_{i,j,m,n,h}$'s equations (9) and (10).

Dynamics

Extending the comparative-static framework used in the above-Bonneville analysis to a dynamic analysis has three basic justifications. The first is that numerical objectives for each stock may change over time. For example, planners may desire a terminal harvest of 1000 fish in year 5, 2500 fish in year 10, and 3000 fish in years 15 and higher. Second, many management actions have substantial lead times between the initial proposal and full biological effectiveness. For example, if the region decides to implement drawdowns in one or more Snake River reservoirs, it will be some years before new smolt and adult passage facilities are in place and operational. In addition, it is thought that many habitat-improvement projects require several years after completion before they are fully effective. Finally, budget constraints, lack of trained personnel, and other practical problems may prohibit completion of every desirable project in a single year, and models should be adapted to reflect this.

We show in equations (13) through (22) how the static framework could be extended to a dynamic analysis[8]. Variables are all defined as before, except that most variables which appeared in equations (1) through (10) have an additional subscript t to denote the planning period (e.g., from 1 to T) in which the action is implemented. The reader may wish to consult Table B.9 for variable and subscript definitions, as the equations are presented without further explanation.

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[8] This presentation ignores several potential complications discussed in the text which follows.

$$\text{Minimize} \sum_t \sum_m (\text{PASS}_{m,t} * \text{CPASS}_m) + \sum_t \sum_i \sum_n (\text{PROP}_{i,n,t} * \text{CPROP}_{i,n}) \quad (13)$$

$$\forall_t \sum_m \text{PASS}_{,,} = 1 \quad (14)$$

$$\forall_{i,t} \text{SUBPASS}_{i,m,t} = \text{PASS}_{m,t} \quad (15)$$

$$\forall_{j,t} \text{STOCKPASS}_{i,j,m,t} = \text{SUBPASS}_{i,m,t} \quad (16)$$

$$\forall_{i,t} \sum_n \text{PROP}_{i,n,t} = 1 \quad (17)$$

$$\forall_{j,t} \text{STOCKPROP}_{i,j,n,t} = \text{PROP}_{i,n,t} \quad (18)$$

$$\forall_{i,j,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h,t} = \text{STOCKPASS}_{i,j,n,t} \quad (19)$$

$$\forall_{i,j,m} \sum_h \text{MAKEFISH}_{i,j,m,n,h,t} = \text{STOCKPROP}_{i,j,m,t} \quad (20)$$

$$\text{SPAWGOAL}_{i,j,t} = \forall_{m,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h,t} * b_{i,j,m,n,h,t} \quad (21)$$

$$\text{HARVGOAL}_{i,j,t} = \forall_{m,n} \sum_h \text{MAKEFISH}_{i,j,m,n,h,t} * a_{i,j,m,n,h,t} \quad (22)$$

Obviously, numerous complications will arise when extending the problem into a dynamic framework. Among the more pressing problems are the need for more detailed economic, **biological, and planning data, and the much larger potential size of the problem to be addressed in** the cost-effectiveness models. In this appendix, we will touch on the more important problems and suggest how they might be solved. A full explication of the difficulties is left to a later phase of the research.

At present, when an action is implemented, we do not consider design and construction lead-times, whether or not the action can be temporarily suspended or permanently de-commissioned, or whether or not a different action might replace the original at the end of its useful life span. In addition, we do not try to analyze how long the action must be in place before it becomes fully effective, and what its effectiveness might be during the construction phase or at other points before it comes on-line. For a dynamic analysis all these data will need to be generated from empirical experiments or assumed, so that we can trace the economic costs and biological effects of different strategies over time. For example, flow-augmentation measures may be designed and implemented relatively quickly if the regional power producers do not need to bring new capacity (e.g., conservation or gas-fired turbines) on line to compensate for lost energy. In contrast, a major new hatchery may take several years to design and construct, and for both projects, several years will pass before additional adult returns are created, since both passage and propagation actions effectively focus on increasing the number of smolts reaching the ocean. The final complication on the economic side is that there may be budget constraints within each planning period; these could be added to the problem formulation fairly easily.

More detailed data on age-specific population abundances will also be required, to trace the effectiveness of harvest measures, and to judge whether or not sufficient spawners will be available to take advantage of improved hatchery and natural propagation opportunities. As noted above, we will require data on how quickly biological parameters change as a result of management actions. For example, at present, we may say that a habitat improvement action will increase rearing capacity from one million to two million smolts. For the dynamic analysis, we will also need to know how soon the capacity will increase, following the action's completion. Data may be available on this for a few stocks and subbasins, but at this point it appears that we will probably be confined to sensitivity testing (i.e., testing how sensitive the results are to different assumptions regarding timing and effectiveness) for most stocks. Also, it is obvious that time-specific information on objectives would be needed as well; e.g., not just how many fish are desired, but how soon planners want the additional fish to be produced.

The size of the problem may also increase very rapidly, as stocks, actions, and planning periods are added to the analysis, Recall from Chapter 2 that if n actions are analyzed, 2^n strategies will be generated (in the static case.) If there are T planning periods, and each action can be implemented independently in each time period, there will be:

$$2^n + 2^{n^2} + 2^{n^3} + \ldots + 2^{n^T} \tag{23}$$

strategies, which obviously increases very quickly with both actions and planning periods.

While space does not permit a explicating all of the details of the solution to the problem posed by (23), we can outline the more important points. First, we have already noted that substantially more biological data will be required for the dynamic analysis; this will probably preclude analyzing the majority of the stocks considered in the static analysis, and so will reduce the dimensions of the problem considerably. Second, it would probably be prudent to limit the number of planning periods to (say) four or five five-year periods, and so reduce **Tin** equation (23) to no more than four or five. Finally, it seems likely that many of the projected outcomes from strategies in (23) will be infeasible (i.e., will not meet the biological objectives.) This also limits the number of strategies that must be subject to detailed analysis.

In summary, while substantial problems of both data and methodology will need to be overcome, our preliminary look at the problem suggests that these problems can be solved. The potential pay-off for such an undertaking is considerable, in both economic, planning, and research terms.

TABLE B.l
Definitions of Terms Used to Specify Mitigation Options

Term	Definition
Management Action	Smallest single management option that will have a unique effect on a biological parameter; e.g., add screens at a run-of river dam, or add rearing capacity at a hatchery
Passage Strategy	Combination of passage actions; will affect all stocks in the system simultaneously; can only use one passage strategy for the entire system.
Propagation Strategy	Combination of propagation actions; will affect all stocks in a given subbasin simultaneously. Exactly one propagation strategy per subbasin.
Propagation/Terminal Harvest/Passage Alternative	Combination of a system-wide passage strategy, subbasin-specific propagation strategy, and stock- specific terminal harvest rate, for a single stock. The alternative defines all the information necessary to calculate the adults produced for a given stock. Generated by the deterministic simulalion model.
System-Wide Strategy	Combination of propagation/terminal harvest/passage alternatives for all stocks in the model. All stocks use the same passage strategy and all stocks within a given subbasin use the same propagation strategy, although different stocks in the same subbasin may have different terminal harvest rates.
System-Wide Least-Cost Strategy	The system-wide strategy which meets a set of biological objectives at the lowest possible cost of subbasin-specific propagation strategies and one passage strategy. Generated by the linear programming model, using alternatives generated by the deterministic simulation model.

TABLE B.2
Example Propagation 'Strategies, Passage Strategies, and Terminal Harvest Alternatives

Subbasin	Propagation Strategies	Passage Strategies	Summer Steelhead Terminal Harvest Rates	Spring Chinook Terminal Harvest Rates	Propagation-Terminal Harvest-Passage Alternatives
Clearwater	Base Case, Habitat Improvement	Base Case, Passage Improvement	20 %, 40 %	20%, 40%	16
Deschutes	Base Case, Habitat Improvement	Base Case, Passage Improvement	20%,40%	20%, 40%	16

TABLE H.3
Results from the Deterministic Life Cycle Model

Subbasin	Passage Strategy	Prop. Strategy	SPC* Harvest Goal	SPC Harvest	SPC Spawn Goal	SPC' Spawn	SSH' Harvest Goal	SSH' Harvest	SSH' Spawn Goal	SSH* Spawn
Clearwater	Base Case	Improved	50,000	16,471	3,000	4,805	74,000	42,668	12,000	13,724
Clear-water	Base Case	Improved	50,000	45,179	3,000	3,234	74,000	83,209	12,000	12,062
Clearwater	Base Case	Base Case	50,000	7,936	3,000	2,292	74,000	42,557	12,000	13,401
Clear-water	Base Case	Base Case	50,000	20,856	3,000	1,491	74,000	82,990	12,000	9,837
Clear-water	Improved	Improved	50,000	18,362	3,000	5,466	74,090	47,438	12,000	15,344
Clearwater	Improved	Improved	50,000	50,059	3,000	3,662	74,000	92,515	12,000	11,274
Clear-water	Improved	Base Case	50,000	8,866	3,000	2,643	74,000	47,314	12,000	14,979
Clear-water	Improved	Base Case	50,000	23,129	3,000	1,702	,74,000	92,270	12,000	11,017
Deschutes	Base Case	Improved	4,000	5,444	1,950	3,152	25,000	28,864	6,000	12,912
Deschutes	Base Case	Improved	4,000	6,776	1,950	2,265	25,000	31,629	6,000	7,786
Deschutes	BaseCase	BaseCase	4,000	3,750	1,950	1,939	25,000	27,642	6,000	6,347
Deschutes	BaseCase	BaseCase	4,000	4,689	1,950	1,338	25,000	29,232	6,000	4,439
Deschutes	Improved	Improved	4,000	5,968	1,950	3,385	25,000	30,962	6,000	11,780
Deschutes	Improved	Improved	4,000	7,407	1,950	2,439	25,000	33,971	6,000	8,439
Deschutes	Improved	Base Case	4,000	4,115	1,950	2,096	25,000	29,649	6,000	6,880
Deschutes	Improved	Base Case	4,000	5,146	1,950	1,457	25,000	31,394	6,000	4,838

* SPC and SSH represent Spring Chinook and Summer Steelhead, respectively

TABLE B.4
Feasibility of Alternatives by Stock

Passage Strategy	Subbasin'	Species+	Propagation Strategy	Terminal Harvest Rate	Meets Terminal Harvest Goal?	Meets Spawning Escapement Goal?
Base Case	CL	SPC	Base Case	20	NO	NO
Base Case	CL	SPC	Base Case	40	NO	NO
Base Case	**CL**	SPC	Habitat Improvement	20	NO	**YES**
Base Case	CL	SPC	Habitat Improvement	40	NO	**YES**
Base Case	CL	SSH	Base Case	20	NO	**YES**
Base Case	CL	SSH	Base Case	40	**YES**	NO
Base Case	CL	SSH	Habitat Improvement	20	NO	**YES**
Base Case	CL	SSH	Habitat Improvement	40	**YES**	**YES**
Base Case	DE	SPC	Base Case	20	NO	NO
Base Case	DE	SPC	Base Case	40	**YES**	NO
Base Case	DE	SPC	Habitat Improvement	20	**YES**	**YES**
Base Case	DE	SPC	Habitat Improvement	40	**YES**	**YES**
Base Case	DE	SSH	Base Case	20	**YES**	**YES**
Base Case	DE	SSH	Base Case	40	**YES**	NO
Base Case	DE	SSH	Habitat Improvement	20	**YES**	**YES**
Base Case	DE	SSH	Habitat Improvement	40	**YES**	**YES**
Improved	**CL**	SPC	Base Case	20	NO	NO
Improved	CL	SPC	Base Case	40	NO	NO
Improved	CL	SPC	Habitat Improvement	20	NO	**YES**
Improved	CL	SPC	Habitat Improvement	40	**YES**	**YES**
Improved	CL	SSH	Base Case	20	NO	**YES**
Improved	CL	SSH	Base Case	40	**YES**	**YES**
Improved	CL	SSH	Habitat Improvemeni	20	NO	**YES**
Improved	CL	SSH	Habitat Improvement	40	**YES**	**YES**
Improved	DE	SPC	Base Case	20	**YES**	**YES**
Improved	DE	SPC	Base Case	40	**YES**	NO
Improved	DE	SPC	Habitat Improvement	20	**YES**	**YES**
Improved	DE	SPC	Habitat Improvement	40	**YES**	**YES**
Improved	DE	SSH	Base Case	20	**YES**	**YES**
Improved	DE	SSH	Base Case	40	**YES**	NO
Improved	DE	SSH	Habitat Improvement	20	**YES**	**YES**
Improved	DE	SSH	Habitat Improvement	40	**YES**	**YES**

· CL and DE represent the Clearwater and Deschutes basins, respectively
+ SPC and SSH represent Spring Chinook and Summer Steelhead, respectively

TABLE B.5
Feasible Alternatives Only

Passage Strategy	Subbasin'	Species+	Propagation Strategy	Terminal Harvest Rate	Meets Terminal Harvest Goal?	Meets Spawning Escapement Goal?
Base Case	CL	SSH	Habitat Improvement	40	**YES**	YES
Base Case	DE	SPC	Habitat Improvement	20	**YES**	YES
Base Case	DE	SPC	Habitat Improvement	40	**YES**	YES
Base Case	DE	SSH	Base Case	20	**YES**	YES
Base Case	DE	SSH	Habitat Improvement	20	**YES**	YES
Base Case	DE	SSH	Habitat Improvement	40	**YES**	YES
Improved	CL	SPC	Habitat Improvement	40	**YES**	YES
Improved	CL	SSH	Base Case	40	**YES**	YES
Improved	CL	SSH	Habitat Improvement	40	**YES**	YES
Improved	DE	SPC	Base Case	20	**YES**	YES
Improved	DE	SPC	Habitat Improvement	20	**YES**	YES
Improved	DE	SPC	Habitat Improvement	40	**YES**	YES
Improved	DE	SSH	Base Case	20	**YES**	YES
Improved	DE	SSH	Habitat Improvement	20	**YES**	YES
Improved	DE	SSH	Habitat Improvement	40	**YES**	YES

∗   **CL and DE represent the Clearwater aud Deschutes basins, respectively**
‡   SPC and SSH represent Spring Chinook and Summer Steelhead, respectively

TABLE B.6
System-Wide Feasible Alternatives Only

Passage Strategy	Subbasin'	Species+	Propagation Strategy	Terminal Harvest Rate	Meets Terminal Harvest Goal?	Meets Spawning Escapement Goal ?
Improved	CL	SPC	Habitat Improvement	40	YES	YES
Improved	CL	SSH	Habitat Improvement	40	YES	YES
Improved	DE	SPC	BaseCase	20	YES	YES
Improved	DE	SPC	Habitat Improvement	20	YES	YES
Improved	DE	SPC	Habitat Improvement	40	YES	YES
Improved	DE	S S H	BaseCase	20	YES	YES
Improved	DE	SSH	HabitaL Improvement	20	YES	YES
Improved	DE	SSH	Habitat Improvement	40	YES	YES

- CL and DE represent the Clearwater and Deschutes basins, respectively
+ SPC and SSH represent Spring Chinook and Summer Steelhead, respectively

TABLE B.7
System-Wide Cost-Effectiveness Strategy

Passage Strategy	Subbasin[*]	Species[+]	Propagation Strategy	Terminal Harvest Rate	Meets Terminal Harvest Goal?	Meets Spawning Escapement Goal ?
Improved	CL	SPC	Habitat Improvement	40	YES	YES
Improved	CL	SSH	Habitat Improvement	40	YES	YES
Improved	DE	SPC	Base Case	20	YES	YES
Improved	DE	SSH	Base Case	20	YES	YES

[*]   CL and DE represent the Clearwater and Deschutes basins, respectively
[+]   SPC and SSH represent Spring Chinook and Summer Steelhead, respectively

TABLE B.8
Optimization Model Terminology

Term	Definition
Objective Function	Function that the optimization tries to minimize, within bounds established by a set of constraints.
Constraint	An equation or expression used to establish limits on what the optimization can do.
Mass-Balance Constraint	Used to ensure internal consistency in the optimization, so that all stocks in the system use the same downstream passage strategy, or all stocks in the same **subbasin** use the same propagation strategy.
Activity	A variable whose value is set by the optimization model as in selecting the least cost strategy (e.g., whether or not to use a particular passage strategy, or at what rate to harvest a particular stock. Also known as a decision variable.
RHS	Abbreviation for "Right Hand Side." Determines how much of each activity must be undertaken. In the current problem, always set to zero or one.
Coefficient	Used to **define** the relationship between activities and constraints. Always set to -1, 0, or **+1** in the current problem.
Tableau	Computerized representation of the objective function, activities, constraints, **coefficients,** and **RHS** values.

TABLE B.9
Optimization Model Variable and Subscript Definitions

Variable	Type[*]	Definition
PASS,	Activity	Propagation strategy
$PROP_{i,n}$	Activity	Passage strategy
$CPASS_m$	Objective Function Coefficient	Cost of passage strategy, annualized dollars
$CPROP_{i,n}$	Objective Function Coefficient	Cost of propagation strategy, annualized dollars
$SUBPASS_{i,m}$	Activity	Subbasin-specific passage capacity
$STOCKPASS_{i,j,m}$	Activity	Stock-specific passage capacity
$STOCKPROP_{i,j,n}$	Activity	Stock-specific propagation capacity
$MAKEFISH_{i,j,m,n,h}$	Activity	Stock-specific fish production activity
$HARVGOAL_{i,j}$	Constraint	Stock-specific harvest goal (1 if **subbasin** planners established a harvest goal for the stock, 0 otherwise)
$SPAWGOAL_{i,j}$	Constraint	Stock-specific spawning escapement goal (1 if **subbasin** planners established a harvest goal for the stock, 0 otherwise)
$i = 1,...,I$	Subscript	Subbasins
$j = 1,...,J$	Subscript	Stocks (note that J will vary with the number of stocks in each subbasin)
$m = 1,...,M$	Subscript	Passage Strategies
$n = 1,...,N$	Subscript	Propagation Strategies (note that N will vary with the number of propagation strategies in each subbasin)
$h = 0,20,...,80$	Subscript	Terminal harvest rates for each stock, in 20 percent increments.

[*]   The different types of variables are defined in Table B.8

TABLE B.10
Costs of Strategies for Heuristic Example

Strategy	Annual Cost ($ millions)
Deschutes Propagation Improvement	0.30
Base Case Passage	0
Passage Improvements	9
Clearwater Base Case Propagation	0
Cleat-water Propagation Improvement	0.41
Deschutes Base Case Propagation	0

TABLE B.11
Tableau for Heuristic Example

LP Equation Number	Row I Equation Name	Right-hand Side	PASS_BASE (BASE-CASE PASSAGE STRATEGY)	IMPRPASS (IMPROVED PASSAGE STRATEGY)	PROP_DE_BASE (DESCHUTES BASE CASE PROPAGATION STRATEGY)	PROP_DE_IMPROVED (DESCHUTES IMPROVED PROPAGATION STRATEGY)	PROP_CL_BASE (CLEARWATER BASE CASE PROPAGATION STRATEGY)	PROP_CL_IMPROVED (CLEARWATER IMPROVED PROPAGATION STRATEGY)	SUBPASS_DE_BASE (DESCHUTES SUBBASIN PASSAGE, BASE CASE)	SUBPASS_DE_IMPRPASS (DESCHUTES SUBBASIN PASSAGE IMPROVED)	SUBPASS_CL_BASE (CLEARWATER SUBBASIN PASSAGE BASE CASE)	SUBPASS_CL_IMPRPASS (CLEARWATER SUBBASIN PASSAGE, IMPROVED)	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH2ᵉ	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SSᵃ ASEPASS_IMPROP_TH2ᵉ
1	OBJRow	N	0.00	9.00	0.00	0.30	0.00	0.41															
2	PASS_SOS_ROW	1	1	1																			
3	DE_PASS_BASE	0	1						-1														
3	DE_IMPRPASS	0		1						-1													
3	CL_PASS_BASE	3	1								-1												
3	CL_IMPRPASS	0		1								-1											
4	E_SPC_BASEPASS_ROW	0							1				-1	-1	-1	-1							
4	E_SSH_BASEPASS_ROW	0							1												-1	-1	-1
4	E_SPC_IMPRPASS_ROW	0								1							-1	-1	-1	-1			
4	DE_SSH_IMPRPASS_ROW	0								1													

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TABLE B.ll
Tableau for Heuristic Example

LP Equation Number	Row / Equation Name	Right-hand Side	PASS_BASE (BASE-CASE PASSAGE STRATEGY)	IMPRPASS (iMPROVED PASSAGE STRATEGY)	PROP_DE_BASE (DESCHUTES BASE CASE PROPAGATION STRATEGY)	PROP_DE_IMPROVED (DESCHUTES IMPROVED PROPAGATION STRATEGY)	PROP_CL_BASE (CLEARWATER BASE CASE PROPAGATION STRATEGY)	PROP_CL_IMPROVED (CLEARWATER IMPROVED PROPAGATION STRATE)	SUBPASS_DE_BASE (DESCHUTES SUBBASIN PASSAGE, BASE CASE)	SUBPASS_DE_IMPRPASS (DESCHUTES SUBBASIN PASSAGE, IMPROVED)	SUBPASS_CL_BASE (CLEARWATER SUBBASIN PASSAGE, BASE CASE)	SUBPASS_CL_IMPRPASS (CLEARWATER SUBBASIN PASSAGE IMPROVED)	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SSX_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH20
1	OBJROW	N	0.00	9.00	0.00	0.30	0.00	0.4															
4	CL_SPC_BASEPASS_ROW	0									1												
4	CL_SSH_BASEPASS_ROW	0									1												
4	CL_SPC_IMPRPASS_ROW	0										1											
4	CL_SSH_IMPRPASS_ROW	0										1											
5	DE_PROP_SOS	1			1	1																	
5	CL_PROP_SOS	1					1	1															
6	DE_SPC_BASEPROP_ROW	0			1								-1	-1			-1	-1					
6	DE_SSH_BASEPROP_ROW	0			1																-1	-1	
6	DE_SPC_IMPROP_ROW	0			1										-1	-1			-1	-1			

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LP Equation Number	Row I Equation Name	Right-hand Side	PASS_BASE (BASE-CASE PASSAGE STRATEGY)	IMPRPASS (IMPROVED PASSAGE STRATEGY)	PROP_DE_BASE (DESCHUTES BASE CASE PROPAGATION STRATEGY)	PROP_DE_IMPROVED (DESCHUTES IMPROVED PROPAGATION STRATEGY)	PROP_CL_BASE (CLEARWATER BASE CASE PROPAGATION STRATEGY)	PROP_CL_IMPROVED (CLEARWATER IMPROVED PROPAGATION STRATE)	SUBPASS_DE_BASE (DESCHUTES SUBBASIN PASSAGE, BASE CASE)	SUBPASS_DE_IMPRPASS (DESCHUTES SUBBASIN PASSAGE, IMPROVED)	SUBPASS_CL_BASE (CLEARWATER SUBBASIN PASSAGE, BASE CASE)	SUBPASS_CL_IMPRPASS (CLEARWATER SUBBASIN PASSAGE, IMPROVED)	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH20
1	OBJROW	N	0.00	9.00	0.00	0.30	0.00	0.41															
6	DE_SSH_IMPROP_ROW	0				1																	-1
6	CL_SPC_BASEPROP_ROW	0					1																
6	CL_SSH_BASEPROP_ROW	0					1																
6	CL_SPC_IMPROP_ROW	0						1															
6	CL_SSH_IMPROP_ROW	0						1															
9	DE_SPC_TERMHARVGOAL	1											0	1	1	1	1	1	1	1			
9	DE_SSH_TERMHARVGOAL	1																			1	1	1
9	CL_SPC_TERMHARVGOAL	1																					
9	CL_SSH_TERMHARVGOAL	1																					

TABLE B.11
Tableau for Heuristic Example

LP Equation Number	Row / Equation Name	Right-hand Side	PASS_BASE (BASE-CASE PASSAGE STRATEGY)	IMPRPASS (IMPROVED PASSAGE STRATEGY)	PROP_DE_BASE (DESCHUTES BASE CASE PROPAGATION STRATEGY)	PROP_DE_IMPROVED (DESCHUTES IMPROVED PROPAGATION STRATEGY)	PROP_CL_BASE (CLEARWATER BASE CASE PROPAGATION STRATEGY)	PROP_CL_IMPROVED (CLEARWATER IMPROVED PROPAGATION STRATE)	SUBPASS_DE_BASE (DESCHUTES SUBBASIN PASSAGE, BASE CASE)	SUBPASS_DE_IMPRPASS (DESCHUTES SUBBASIN PASSAGE, IMPROVED)	SUBPASS_CL_BASE (CLEARWATER SUBBASIN PASSAGE, BASE CASE)	SUBPASS_CL_IMPRPASS (CLEARWATER SUBBASIN PASSAGE, IMPROVED)	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_DE_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH20
1	OBJROW	N	0.00	9.00	0.00	0.30	0.00	0.41															
10	DE_SPC_SPAWNGOAL	1											0	0	1	1	1	0	1				
10	DE_SSH_SPAWNGOAL	1																				0	
10	CL_SPC_SPAWNGOAL	1																					
10	CL_SSH_SPAWNGOAL	1																					

TABLE B.ll
Tableau for Heuristic Example

Number / Row / Equation Name	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH2□	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH40	MA...6 SH_CL_SSH_BASEPASS_BASEPROP_TH2□	MAKEFISH_CL_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH20	MA...6 SH_CL_SSH_IMPRPASS_IMPROP_TH40
1 BJROW																					
2 PASS-SOS-ROW																					
3 DE-PASS-BASE																					
3 DE_IMPRPASS																					
3 CL_PASS_BASE																					
3 CL_IMPRPASS																					
4 I DE_SPC_BASEPASS_ROW																					
4 DE_SSH_BASEPASS_ROW	-1																				
4 DE_SPC_IMPRPASS_ROW																					
4 DE_SSH_IMPRPASS_ROW		-1	-1	-1	-1																

TABLE B.ll
Tableau for Heuristic Example

LP Equation Number	Row I Equation Name	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_IMPROP TH20	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_IMPROP TH40	MAKEFIS□ CI_SSH BASEPASS_BASEPROP_TH20	MAKEFIS×_CL SS× BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_IMPROP TH20	MAKEFISH_CL_SS×_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH2□	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH40
1	OBJROW																					
4	L_SPC_BASEPASS_ROW						-1	-1	-1	-1												
4	L_SSH_BASEPASS_ROW														-1	-1	-1	-1				
4	L_SPC_IMPRPASS_ROW										-1	-1	-1	-1								
4	L_SSH_IMPRPASS_ROW																		-1	-1	-1	-1
5	OE_PROP_SOS																					
5	Z-PROP-SOS																					
6	OE_SPC_BASEPROP_ROW																					
6	OE_SSH_BASEPROP_ROW	-1	-1																			
6	OE_SPC_IMPROP_ROW																					

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LP Equation Number	Row I Equation Name	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH40
1	OBJROW																					
6	DE_SSH_IMPROP_ROW	-1			-1	-1																
6	CL_SPC_BASEPROP_ROW						-1	-1			-1	-1										
6	CL_SSH_BASEPROP_ROW														-1	-1			-1	-1		
6	CL_SPC_IMPROP_ROW								-1	-1			-1	-1								
6	CL_SSH_IMPROP_ROW																-1	-1			-1	-1
9	DE_SPC_TERMHARVGOAL																					
9	DE_SSH_TERMHARVGOAL	1	1	1	1	1																
9	CL_SPC_TERMHARVGOAL						0	0	0	0	0	0	0									
9	CL_SSH_TERMHARVGOAL														0	1	0	1	0	1	0	1

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TABLE B.11
Tableau for Heuristic Example

LP Equation Number	Row / Equation Name	MAKEFISH_DE_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH20	MAKEFISH_DE_SSH_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SPC_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SPC_IMPRPASS_IMPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_BASEPROP_TH20	MAKEFISH_CL_SSH_BASEPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH20	MAKEFISH_CL_SSH_BASEPASS_IMPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH20	MAKEFISH_CL_SSH_IMPRPASS_BASEPROP_TH40	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH20	MAKEFISH_CL_SSH_IMPRPASS_IMPROP_TH40
1	OBJROW																					
10	DE_SPC_SPAWNGOAL																					
10	DE_SSH_SPAWNGOAL	1	1	0	1	1																
10	CL_SPC_SPAWNGOAL						0	0	1	1	0	0	1	1								
10	CL_SSH_SPAWNGOAL															1	0	1	1	1	1	1

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TABLE C.l
Base-Case Propagation Parameters

PARAMETER	GRANDE RONDE		GRANDE RONDE		GRANDE RONDE		CLEARWATER	
	Spring Chinook Natural Value	Spring Chinook Natural source*	spring Chinook Hatchery Value	Spring Chinook Hatchery source*	Summer Steelhead Natural Value	Summer Steelhead Natural source*	Spring Chinook Natural Value	Spring Chinook Natural source*
ffem	0.608	A	0.475	A	0.63	A	0.49	A
prspsv	0.65	A	0.9	A	0.8	A	0.6	A
egfem	3,577.	A	4,023.	A	5,000.	A	4,221.	A
hatrem	183.	Cl	386.	Cl	702.	Cl	992.	Cl
hatsmolt	294,358.	C	619,630.	C	1,555,204.	C	1,464,375.	C
hintsv	0.75	B	0.75	B	0.6	B	0.75	B3
bhincp	0.13	Al	0.838	Al	0.239942	Al	0.163967	Al
bhcap	433,000.	A	--		460,000.	A	5,886,114.	A
smtage 1	1.	A	1.	A	0.6	A	1.	A
smtage2	--	A	--	A	0.4	A	--	A
smtage3	--	A	--	A	--	A	--	A
inbsmsv	0.5	A	0.8	B	0.5	A	0.5	A
adtrecv	0.0825	F	0.01088	F	0.1292	F	0.01425	F
sadtrecv	0.0085	F	--	F	0.01696	F	0.0083	F
ocnlhar	0.001	D	0.001	D	--	D	0.001	D
ocnlrvh	0.011	D	0.011	D	--	D	0.011	D
ocnl suv	0.875	D	0.875	D	0.54542	D	0.875	D
ocn2har	0.004	D	0.004	D	--	D	0.004	D
ocn2rvh	0.11	D	0.11	D	--	D	0.11	D
ocn2suv	0.301	D	0.301	D	0.19132	D	0.301	D
ocn3har	--	D	--	D	--	D	--	D
ocn3rvh	0.389	D	0.389	D	--	D	0.389	D
ocn3suv	0.009	D	0.009	D	0.30567	D	0.009	D
ocn4har	--	D	--	D	--	D	--	D
ocn4rvh	0.8	D	0.8	D	--	D	0.8	D
ocnlsbe	0.113	D	0.113	D	0.45458	D	0.113	D
ocn2sbe	0.585	D	0.585	D	0.80868	D	0.585	D
ocn3sbe	0.602	D	0.602	D	0.69433	D	0.602	D
ocn4sbe	0.2	D	0.2	D	1.	D	0.2	D
termhar	0.03	A	0.03	A	--	A	0.04	A
suptermh	0.03	A	--	A	0.1	A	0.04	A
msurv	0.30131	E	0.24105	E	0.393 14	E	0.56409	E
passcv	0.248485	E	0.248485	E	0.233072	E	0.092341	E
jackspn	--	A	--	A	1.	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	CLEARWATER		CLEARWATER		CLEARWATER		LOWER SALMON	
	Spring Chinook Hatchery Value	Spring Chinook Hatchery sonrce*	Summer Steelhead Natural Value	Summer Steelhead Natural sol.uce*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	Spring Chinook Natural Value	Spring Chinook Natural source*
ffem	0.6	J	0.592352	A	0.6	J	0.547	A
prspsv	0.8	A	0.8	A	0.952	B	0.6	A
egfem	4,100.	J	6,000.	A	6,000.	J	3,912.	A
hatrem	1,112.	Cl	536.	Cl	764.	Cl	0.	
hatsmolt	1642,444.	C	1.122846.	C	1,540,704.	C	0.	
hintsv	0.75	B3	0.6	B3	0.6	B3	0.5	B
bhincp			0.239942	Al			0.163967	Al
bhcap	--		1600,000.	A	--		530,317.	A
smtagel	--		0.2	A	--		1.	A
smtage2	--		0.72	A	--		--	A
smtage3	--		0.08	A	--		--	A
inbsmsv	--		0.5	A	--		0.5	A
adtrecv	0.00459	F	0.0495	F	0.1687	F	0.0405	F
sadtrecv	--	F	0.03 135	F	--	F	NS	F
ocnlbar	0.001	D	--	B2	0.01	D	0.001	D
ocnlrvh	0.011	D	--	B2	0.02	D	0.011	D
ocnlsuv	0.875	D	1.	B2	0.96	D	0.875	D
ocn2har	0.004	D	--	B2	0.01	D	0.004	D
ocn2rvh	0.11	D	--	B2	0.52	D	0.11	D
ocn2suv	0.301	D	1.	B2	0.2	D	0.301	D
ocn3har	--	D	--	B2	--	D	--	D
ocn3rvh	0.389	D	--	B2	0.64	D	0.389	D
ocn3suv	0.009	D	1.	B2	0.03	D	0.009	D
ocn4har	--	D	--	B2	--	D	--	D
ocn4rvh	0.8	D	--	B2	0.61	D	0.8	D
ocnlsbe	0.113	D	--	B2	0.01	D	0.113	D
ocn2sbe	0.585	D	0.	B2	0.27	D	0.585	D
ocn3sbe	0.602	D	0.	B2	0.33	D	0.602	D
ocn4sbe	0.2	D	--	B2	0.39	D	0.2	D
termhar	0.04	A	--	A	0.6	A	--	A
suptermh	--	A	0.6	A	--	A	--	A
msurv	0.45128	E	0.47353	E	0.37883	E	0.34693	E
passcv	0.092341	E	0.211943	E	0.211943	E	0.119771	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	LOWER SALMON Spring Chinook Hatchery Value	Spring Chinook Hatchery source*	LOWER SALMON Summer Steelhead Natural Value	Summer Steelhead Natural source*	LOWER SALMON Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	LITTLE SALMON Spring Chinook Natural Value	Spring Chinook Natural source*
ffem	0.503101	A	0.67	A	0.52825	A	0.50416	A
prspsv	0.819	A	0.8	A	0.9	A	0.6	A
egfem	3,831.	A	3,200.	A	6,468.	A	3,832.	A
hatrem	0.		307.	Cl	6.	Cl	217.	Cl
hatsmolt	0.		629,541.	C	0.		250,000.	C
hintsv	0.5	B	0.65	B	0.65	B	0.5	B
bhincp	0.58	Al	0.239942	Al	0.61	Al	0.163967	Al
bhcap	--		94,949.	A	--		291,103.	A
smtagel	--		0.2	A	--		1.	A
smtage2	--		0.72	A	--		--	A
smtage3	--		0.08	A	--		--	A
inbsmsv	--		0.4	A	--		0.5	A
adtrecv	0.06	F1	0.134	F	0.0907	F1	0.0088	F
sadtrecv	--	F	0.02365	F	--	F	0.0255	F
ocnlhar	0.001	D	--	B2	0.01	D	0.001	D
ocnlrvh	0.011	D	--	B2	0.02	D	0.011	D
ocnlsuv	0.875	D	1.	B2	0.96	D	0.875	D
ocn2har	0.004	D	--	B2	0.01	D	0.004	D
ocn2rvh	0.11	D	--	B2	0.52	D	0.11	D
ocn2suv	0.301	D	1.	B2	0.2	D	0.301	D
ocn3har	--	D	--	B2	--	D	--	D
ocn3rvh	0.389	D	--	B2	0.64	D	0.389	D
ocn3suv	0.009	D	--	B2	0.03	D	0.009	D
ocn4har	--	D	--	B2	--	D	--	D
ocn4rvh	0.8	D	--	B2	0.61	D	0.8	D
ocnlsbe	0.113	D	--	B2	0.01	D	0.113	D
ocn2sbe	0.585	D	0.	B2	0.27	D	0.585	D
ocn3sbe	0.602	D	--	B2	0.33	D	0.602	D
ocn4sbe	0.2	D	--	B2	0.39	D	0.2	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.27754	E	0.46972	E	0.37578	E	0.34693	E
passcv	0.119771	E	0.203222	E	0.203222	E	0.119771	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	LITTLE SALMON		LI'ITLE SALMON		MID MAIN SALMON		MID MAIN SALMON	
	Spring Chinook Hatchery Value	Spring Chinook Hatchery Source*	Summer Steelhead Natural Value	Summer Steelhead Natural sonrce*	Spring Chinook Natural Value	Spring Chinook Natural Source*	Spring Chinook Hatchery Value	Spring Chinook Hatchery Source*
ffem	0.50587	A	0.57 1007	A	0.547	A	0.616944	A
prspsv	0.819	A	0.8	A	0.6	A	0.819	A
egfem	3,912.	A	5,162.	A	4,500.	A	3,427.	A
hatrem	2,195.	Cl	393.	Cl	0.		0.	
hatsmolt	2,520,400.	C	699,317.	C	0.		0.	
hintsv	0.5	B	0.65	B	0.5	B	0.5	B
bhincp	0.58	Al	0.239942	Al	0.16397	Al	0.58	Al
bhcap	--		118,759.	A	505,456.	A	--	
smtagel	--		0.2	A	1.	A	--	
smtage2	--		0.72	A	--	A	--	
smtage3	--		0.08	A	--	A	--	
inbsmsv	--		0.5	A	0.5	A	--	
adtrecv	0.0607	F1	0.137	F	0.0378	F	0.06	F1
sadtrecv	--	F	0.02364	F	NS	F	--	F
ocnlhar	0.001	D	--	B2	0.001	D	0.001	D
ocnlrvh	0.011	D	--	B2	0.011	D	0.011	D
ocnlsuv	0.875	D	1.	B2	0.875	D	0.875	D
ocn2har	0.004	D	--	B2	0.004	D	0.004	D
ocn2rvh	0.11	D	--	B2	0.11	D	0.11	D
ocn2suv	0.301	D	1.	B2	0.301	D	0.301	D
ocn3har	--	D	--	B2	--	D	--	D
ocn3rvh	0.389	D	--	B2	0.389	D	0.389	D
ocn3suv	0.009	D	--	B2	0.009	D	0.009	D
ocn4har	--	D	--	B2	--	D	--	D
ocn4rvh	0.8	D	--	B2	0.8	D	0.8	D
ocnlsbe	0.113	D	--	B2	0.113	D	0.113	D
ocn2sbe	0.585	D	0.	B2	0.585	D	0.585	D
ocn3sbe	0.602	D	--	B2	0.602	D	0.602	D
ocn4sbe	0.2	D	--	B2	0.2	D	0.2	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	0.6	A	--	A	--	A
msurv	0.2432	E	0.46972	E	0.34693	E	0.27754	E
passcv	0.239738	E	0.203222	E	0.119771	E	0.119771	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	MID MAIN SALMON		MID MAIN SALMON		MID FORK SALMON		LEMHI	
	Summer Steelhead Natural Value	Summer Steelhead Natural source*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Spring Chinook Natural Value	Spring Chinook Natural Source*
ffem	0.67	A	0.560785	A	0.547	A	0.5	A
prspsv	0.8	A	0.9	A	0.6	A	0.6	A
egfem	3,200.	A	7,228.	A	5,313.	A	4,787.	A
hatrem	5.	Cl	6.	Cl	0.		0.	
hatsmolt	0.		0.		0.		0.	
hintsv	0.65	B	0.65	B	0.5	B	0.5	B
bhincp	0.239942	Al			0.163967	Al	0.163967	Al
bhcap	186,722.	A	--		3,786,756.	A	715,499.	A
smtagel	0.2	A	--		1.	A	1.	A
smtage2	0.72	A	--		--	A	--	A
smtage3	0.08	A	--		--	A	--	A
inbsmsv	0.4	A	--		0.5	A	0.5	A
adtrecv	0.154	F	0.0907	F1	0.03256	F	0.0386	F
sadtrecv	NS	F	--	F	0.0185	F	0.0185	F
ocnlhar	--	B2	0.01	D	0.001	D	0.001	D
ocnlrvh	--	B2	0.02	D	0.011	D	0.011	D
ocnlsuv	1.	B2	0.96	D	0.875	D	0.875	D
ocn2har	--	B2	0.01	D	0.004	D	0.004	D
ocn2rvh	--	B2	0.52	D	0.11	D	0.11	D
ocn2suv	1.	B2	0.2	D	0.301	D	0.301	D
ocn3har	--	B2	--	D	--	D	--	D
ocn3rvh	--	B2	0.64	D	0.389	D	0.389	D
ocn3suv	--	B2	0.03	D	0.009	D	0.009	D
ocn4har	--	B2	--	D	--	D	--	D
ocn4rvh	--	B2	0.61	D	0.8	D	0.8	D
ocnlsbe	--	B2	0.01	D	0.113	D	0.113	D
ocn2sbe	0.	B2	0.27	D	0.585	D	0.585	D
ocn3sbe	--	B2	0.33	D	0.602	D	0.602	D
ocn4sbe	--	B2	0.39	D	0.2	D	0.2	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.46972	E	0.37578	E	0.34693	E	0.34693	E
passcv	0.203222	E	0.203222	E	0.119771	E	0.119771	E
jackspn	1.	A	--	A	--	A	--	A

TABLE C.1
Base-Case Propagation Parameters

PARAMETER	LEMHI Summer Steelhead Natural Value	Summer Steelhead Natural Source*	UPPER SALMON Spring Chinook Natural Value	Spring Chinook Natural source*	UPPER SALMON Spring Chinook Hatchery Value	Spring Chinook Hatchery Source*	UPPER SALMON Summer Chinook Natural Value	Summer Chinook Natural Source*
ffem	0.5	A	0.473	A	0.45	A	0.553	A
prspsv	0.8	A	0.6	A	0.819	A	0.7	A
egfem	4,374.	A	5,292.	A	5,106.	A	5,000.	A
hatrem	5.	Cl	457.	Cl	1,213.	Cl	0.	
hatsmolt	0.		715,400.	C	**1,895,600.**	C	0.	
hintsv	0.65	B	0.5	B	0.5	B	0.5	B
bhincp	0.239942	Al	0.163967	Al	0.68	Al	0.163967	Al
bhcap	97,998.	A	**1,586,454.**	A	--		976,459.	A
smtage 1	0.2	A	1.	A	--		1.	A
smtage2	0.72	A	--	A	--		--	A
smtage3	0.08	A	--	A	--		--	A
iubsmsv	0.4	A	0.5	A	--		0.5	A
adtrecv	0.154	F	0.0129	F	0.0594	F1	0.034	F
sadtrecv	0.0328	F	0.0255	F	--	F	NS	F
ocnlhar	--	B2	0.001	D	0.001	D	0.002	D
ocnlrvh	--	B2	0.011	D	0.011	D	0.029	D
ocnlsuv	1.	B2	0.875	D	0.875	D	0.678	D
ocn2har	--	B2	0.004	D	0.004	D	0.005	D
ocn2rvh	--	B2	0.11	D	0.11	D	0.15	D
ocn2suv	1.	B2	0.301	D	0.301	D	0.2285	D
ocn3har	--	B2	--	D	--	D	0.009	D
ocn3rvh	--	B2	0.389	D	0.389	D	0.046	D
ocn3suv	--	B2	0.009	D	0.009	D	0.002	D
ocn4har	--	B2	--	D	--	D	--	D
ocn4rvh	--	B2	0.8	D	0.8	D	--	D
ocnlsbe	--	B2	0.113	D	0.113	D	0.29	D
ocn2sbe	0.	B2	0.585	D	0.585	D	0.6165	D
ocn3sbe	--	B2	0.602	D	0.602	D	0.943	D
ocn4sbe	--	B2	0.2	D	0.2	D	1.	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.46972	E	0.34693	E	0.24845	E	0.3405	E
passcv	0.203222	E	0.119771	E	0.238995	E	0.151298	E
jackspn	1.	A	--	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	UPPER SALMON		UPPER SALMON		UPPER SALMON		S. FORK SALMON	
	Summer Chinook Hatchery Value	Summer Chinook Hatchery Source*	Summer Steelhead Natural Value	Summer Steelhead Natural Source*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	Summer Chinook Natural Value	Summer Chinook Natural source*
ffem	0.616944	A	0.497	A	0.570714	A	0.506	A
prspsv	0.893	A	0.8	A	0.9	A	0.7	A
egfem	3,427.	A	4,987.	A	5,159.	A	3,590.	A
hatrem	0.		1,333.	C1	173.	C1	0.	
hatsmolt	0.		2,386,652.	C	301,156.	C	0.	
hintsv	0.5	B	0.65	B	0.65	B	0.5	B
bhincp	0.76	Al	0.239942	Al	0.61	Al	0.163967	Al
bhcap	--		665,466.	A	--		2,092,013.	A
smtagel	--		0.2	A	--		1.	A
smtage2	--		0.72	A	--		--	A
smtage3	--		0.08	A	--		--	A
inbsmsv	--		0.4	A	--		0.5	A
adtrecv	0.0604	F1	0.1324	F	0.0907	F1	0.05 107	F
sadtrecv	--	F	0.02457	F	--	F	NS	F
ocnlhar	0.002	D	--	B2	0.01	D	0.002	D
ocnlrvh	0.029	D	--	B2	0.02	D	0.029	D
ocnlsuv	0.678	D	1.	B2	0.96	D	0.678	D
ocn2har	0.005	D	--	B2	0.01	D	0.005	D
ocn2rvh	0.15	D	--	B2	0.52	D	0.15	D
ocn2suv	0.2285	D	1.	B2	0.2	D	0.2285	D
ocn3har	0.009	D	--	B2	--	D	0.009	D
ocn3rvh	0.046	D	--	B2	0.64	D	0.046	D
ocn3suv	0.002	D	--	B2	0.03	D	0.002	D
ocn4har	--	D	--	B2	--	D	--	D
ocn4rvh	--	D	--	B2	0.61	D	--	D
ocnlsbe	0.29	D	--	B2	0.01	D	0.29	D
ocn2sbe	0.6165	D	0.	B2	0.27	D	0.6165	D
ocn3sbe	0.943	D	--	B2	0.33	D	0.943	D
ocn4sbe	1.	D	--	B2	0.39	D	1.	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.2724	E	0.45188	E	0.37578	E	0.3405	E
passcv	0.151298	E	0.203222	E	0.203222	E	0.151298	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	S. FORK SALMON		S. FORK SALMON		S. FORK SALMON		PANTHER CREEK	
	Summer Chinook Hatchery Value	Summer Chmook Hatchery source*	Summer Steelhead Natural Value	Summer Steelhead Natural source*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	Summer Chinook Natural Value	Summer Chinook Natural Source*
ffem	0.33848	A	0.488	A	0.560785	A	0.41492	A
prspsv	0.893	A	0.8	A	0.9	A	0.7	A
egfem	4,382.	A	5,600.	A	7,228.	A	5,527.	A
hatrem	994.	Cl	5.	Cl	6.	Cl	0.	
hatsmolt	1,032,500.	C	0.		0.		0.	
hintsv	0.5	B	0.65	B	0.65	B	0.5	B
bhincp	0.7	Al	0.239942	Al	0.54	Al	0.163967	Al
bhcap	--		445,209.	A	--		42,769.	A
smtage 1	--		0.2	A	--		1.	A
smtage2	--		0.72	A	--		--	A
smtage3	--		0.08	A	--		--	A
inbsmsv	--		0.4	A	--		0.5	A
adtrecv	0.0602	F1	0.05	F	0.0907	F1	0.0403	F
sadtrecv	--	F	NS	F	--	F	0.0173	F
ocnlhar	0.002	D	--	B2	0.01	D	0.002	D
ocnlrvh	0.029	D	--	B2	0.02	D	0.029	D
ocnlsuv	0.678	D	1.	B2	0.96	D	0.678	D
ocn2har	0.005	D	--	B2	0.01	D	0.005	D
ocn2rvh	0.15	D	--	B2	0.52	D	0.15	D
ocn2suv	0.2285	D	1.	B2	0.2	D	0.2285	D
ocn3har	0.009	D	--	B2	--	D	0.009	D
ocn3rvh	0.046	D	--	B2	0.64	D	0.046	D
ocn3suv	0.002	D	--	B2	0.03	D	0.002	D
ocn4har	--	D	--	B2	--	D	--	D
ocn4rvh	--	D	--	B2	0.61	D	--	D
ocnlsbe	0.29	D	--	B2	0.01	D	0.29	D
ocn2sbe	0.6165	D	0.	B2	0.27	D	0.6165	D
ocn3sbe	0.943	D	--	B2	0.33	D	0.943	D
ocn4sbe	1.	D	--	B2	0.39	D	1.	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.2452	E	0.46972	E	0.37578	E	0.3405	E
passcv	0.242227	E	0.203222	E	0.203222	E	0.151298	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	PANTHER CREEK		PANTHER CREEK		PAHSIMEROI		PAHSIMEROI	
	Summer Steelhead Natural Value	Summer Steelhead Natural Source*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery source*	Summer Chinook Natural Value	Summer Chinook Natural source*	Summer Chinook Hatchery Value	Summer Chinook Hatchery source*
ffem	0.570333	A	0.570781	A	0.553	A	0.36715	A
prspsv	0.8	A	0.9	A	0.7	A	0.893	A
egfem	5,155.	A	5,160.	A	5,255.	A	5,448.	A
hatrem	5.	Cl	6.	Cl	0.		695.	Cl
hatsmolt	0.		0.		0.		1,058,000.	C
hintsv	0.65	B	0.65	B	0.5	B	0.5	B
bhincp	0.239942	Al	0.65	Al	0.163967	Al	0.76	Al
bhcap	8,201.	A	--		257,620.	A	--	
smtagel	0.2	A	--		1.	A	--	
smtage2	0.72	A	--		--	A	--	
smtage3	0.08	A	--		--	A	--	
inbsmsv	0.5	A	--		0.5	A	--	
adtrecv	0.15	F	0.0907	F1	0.03 14	F	0.0606	F1
sadtrecv	NS	F	--	F	NS	F	--	F
ocn1har	--	B2	0.01	D	0.002	D	0.002	D
ocnlrvh	--	B2	0.02	D	0.029	D	0.029	D
ocnlsuv	1.	B2	0.96	D	0.678	D	0.678	D
ocn2har	--	B2	0.01	D	0.005	D	0.005	D
ocn2rvh	--	B2	0.52	D	0.15	D	0.15	D
ocn2suv	1.	B2	0.2	D	0.2285	D	0.2285	D
ocn3har	--	B2	--	D	0.009	D	0.009	D
ocn3rvh	--	B2	0.64	D	0.046	D	0.046	D
ocn3suv	--	B2	0.03	D	0.002	D	0.002	D
ocn4har	--	B2	--	D	--	D	--	D
ocn4rvh	--	B2	0.61	D	--	D	--	D
ocnlsbe	--	B2	0.01	D	0.29	D	0.29	D
ocn2sbe	0.	B2	0.27	D	0.6165	D	0.6165	D
ocn3sbe	--	B2	0.33	D	0.943	D	0.943	D
ocn4sbe	--	B2	0.39	D	1.	D	1.	D
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	--	A
msurv	0.46972	E	0.37578	E	0.3405	E	0.2437	E
passcv	0.203222	E	0.203222	E	0.151298	E	0.244146	E
jackspn	1.	A	--	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	PAHSIMEROI Summer Steelhead Natural Value	Summer Steelhead Natural source*	PAHSIMEROI Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	TUCANNON Spring Chinook Natural Value	Spring Chinook Natural source*	TUCANNON Summer Steelhead Natural Value	Summer Steelhead Natural source*
ffem	0.596	A	0.570656	A	0.5225	A	0.77	B
prspsv	0.8	A	0.9	A	0.6	B	0.8	A
egfem	4,374.	A	5,158.	A	4,050.	A	5,347.	B
hatrem	284.	Cl	6.	Cl	72.	Cl	2.	Cl
hatsmolt	501,600.	C	0.		145,146.	C	0.	
hintsv	0.65	B	0.65	B	0.75	B	0.71	B
bhincp	0.239942	Al	0.61	Al	0.16	A2	0.0322	Al
bhcap	29,930.	A	--		180,000.	A	49,100.	A
smtagel	0.2	A	--		1.	A2	0.1	A
smtage2	0.72	A	--		--	A2	0.9	A
smtage3	0.08	A	--		--	A2	--	A
inbsmsv	0.4	A	--		0.5	A2	0.5	A2
adtrecv	0.131	F	0.0907	F1	0.078	F	0.253	F
sadtrecv	NS	F	--	F	0.0575	F	0.28	F
ocnlhar	--	B2	0.01	D	0.001	D	--	B2
ocnlrvh	--	B2	0.02	D	0.011	D	--	B2
ocnlsuv	1.	B2	0.96	D	0.875	D	1.	B2
ocn2har	--	B2	0.01	D	0.004	D	--	B2
ocn2rvh	--	B2	0.52	D	0.11	D	--	B2
ocn2suv	1.	B2	0.2	D	0.301	D	1.	B2
ocn3har	--	B2	--	D	--	D	--	B2
ocn3rvh	--	B2	0.64	D	0.389	D	--	B2
ocn3suv	--	B2	0.03	D	0.009	D	1.	B2
ocn4har	--	B2	--	D	--	D	--	B2
ocn4rvh	--	B2	0.61	D	0.8	D	--	B2
ocnlsbe	--	B2	0.01	D	0.113	D	--	B2
ocn2sbe	0.	B2	0.27	D	0.585	D	0.	B2
ocn3sbe	--	B2	0.33	D	0.602	D	0.	B2
ocn4sbe	--	B2	0.39	D	0.2	D	--	B2
termhar	--	A	--	A	--	A	--	A
suptermh	--	A	--	A	--	A	0.8	A
msurv	0.46972	E	0.37578	E	0.25805	E	0.35703	E
passcv	0.203222	E	0.203222	E	0.213465	E	0.157409	E
jackspn	1.	A	--	A	--	A	1.	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	TUCANNON		IMNAHA		DESCHUTES		DESCHUTES	
	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Spring Chinook Natural Value	Spring Chinook Natural Source*	Spring Chinook Hatchery Value	Spring Chinook Hatchery source*
ffem	0.77	A	0.414	A	0.62	A	0.616944	B
prspsv	0.9	B	0.65	A	0.56	B	0.85	B
egfem	4,262.	A	4,805.	A	3,300.	A	3,427.	B
hatrem	46.	Cl	327.	Cl	0.		553.	Cl
hatsmolt	119,264.	C	444,462.	C	0.		968,603.	C
hintsv	0.71	B	0.8	B	0.5	B	0.5	B
bhincp			0.13	Al	0.15	B	.	
bhcap	--		245,260.	A	140,125.	A	--	
smtagel	--		1.	A	1.	A	--	
smtage2	--		--	A	--	A	--	
smtage3	--		--	A	--	A	--	
inbsmsv	--		0.5	A	0.5	A2	--	
adtrecv	0.0557	F	0.119	F	0.266	F	0.0215	F
sadtrecv	--	F	0.0074	F	NS	F	--	F
ocnlhar	0.01	D	0.001	D	0.0018	D	0.0018	D
ocnlrvh	0.02	D	0.011	D	0.09883	D	0.09883	D
ocnlsuv	0.96	D	0.875	D	0.77242	D	0.77242	D
ocn2har	0.01	D	0.004	D	0.00466	D	0.00466	D
ocn2rvh	0.52	D	0.11	D	0.37788	D	0.37788	D
ocn2suv	0.2	D	0.301	D	0.11589	D	0.11589	D
ocn3har	--	D	--	D	0.00787	D	0.00787	D
ocn3rvh	0.64	D	0.389	D	0.4287	D	0.4287	D
ocn3suv	0.03	D	0.009	D	0.04637	D	0.04637	D
ocn4har	--	D	--	D	0.07547	D	0.07547	D
ocn4rvh	0.61	D	0.8	D	0.49057	D	0.49057	D
ocnlsbe	0.01	D	0.113	D	0.12695	D	0.12695	D
ocn2sbe	0.27	D	0.585	D	0.50157	D	0.50157	D
ocn3sbe	0.33	D	0.602	D	0.51706	D	0.51706	D
ocn4sbe	0.39	D	0.2	D	0.43396	D	0.43396	D
termhar	0.8	A	--	A	0.29	A	0.31	A
suptermh	--	A	--	A	0.29	A	--	A
msulv	0.28859	E	0.21672	E	0.6308	E	0.4975	E
passcv	0.155999	E	0.034943	E	0.092341	E	0.104338	E
jackspn	--	A	--	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	DESCHUTES Fall Chinook Natural Value	Fall Chinook Natural source*	DESCHUTES Summer Steelhead Natural Value	Summer Steelhead Natural Source*	DESCHUTES Summer Steelhead Hatchery Value	Summer Steelhead Hatchery Source*	WALLA WALLA Spring Chinook Natural Value	Spring Chinook Natural source*
ffem	0.422285	B	0.672	A	0.615	A	0.657802	B
prspsv	0.95	B	0.863	B	0.8	B	0.5	B
egfem	4,922.	B	5,341.	A	4,860.	A	4,733.	B
hatrem	0.		0.		73.	Cl	0.	
hatsmolt	0.		0.		161,608.	C	0.	
hintsv	0.1	B	0.5	B	0.5	B	0.5	B3
bhincp	0.3113	B	0.032	B			0.16	B
bhcap	2,418,387.	A	147,659.	A	--		63,650.	A
smtagel	0.04	A	0.29	J	--		1.	A2
smtage2	--	A	0.55	J	--		--	A2
smtage3	--	A	0.16	J	--		--	A2
inbsmsv	0.5	A2	0.793	B	--		0.5	A2
adtrecv	0.09762	F	0.1628	F	0.876	F	0.3978	F
sadtrecv	NS	F	NS	F	--	F	0.073	F
ocnlhar	0.03081	D	--	B2	--	D	0.0018	D
ocnlrvh	0.01631	D	--	B2	0.1519	D	0.09883	D
ocnlsuv	0.94491	D	1.	B2	0.51899	D	0.77242	D
ocn2har	0.22679	D	--	B2	0.0122	D	0.00466	D
ocn2rvh	0.13467	D	--	B2	0.34756	D	0.37788	D
ocn2suv	0.60055	D	1.	B2	--	D	0.11589	D
ocn3har	0.28733	D	--	B2	--	D	0.00787	D
ocn3rvh	0.36056	D	--	B2	--	D	0.4287	D
ocn3suv	0.26433	D	--	B2	--	D	0.04637	D
ocn4har	0.39795	D	--	B2	--	D	0.07547	D
ocn4rvh	0.50608	D	--	B2	--	D	0.49057	D
ocnlsbe	0.00797	D	--	B2	0.32911	D	0.12695	D
ocn2sbe	0.03798	D	0.	B2	0.64024	D	0.50157	D
ocn3sbe	0.08777	D	0.	B2	--	D	0.51706	D
ocn4sbe	0.09597	D	--	B2	--	D	0.43396	D
termhar	0.3	A	0.1475	A	0.38	A	--	A
suptermh	0.3	A	0.1475	A	--	A	--	A
msurv	0.47771	E	0.6471	E	0.51295	E	0.24458	E
passcv	0.18197	E	0.129311	E	0.135635	E	0.192582	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	WALLA WALLA		UMATILLA		UMATILLA		UMATILLA	
	Summer Steelbead Natural Value	Summer Steelhead Natural source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Fall Chinook Natural Value	Fall Chinook Natural source*	Summer Steelbead Natural Value	Summer Steelbead Natural source*
ffem	0.8	A	0.657802	B	0.618565	B	0.63	A
prspsv	0.8	B	0.5	B	0.5	B	0.8	B
egfem	3,975.	A	4,733.	B	4,608.	B	5,268.	A
hatrem	0.	Cl	818.	Cl	3,404.	Cl	129.	Cl
hatsmolt	278,762.	C	1,700,000.	CIA	7,000,000.	CIA	239,193.	C/A
hintsv	0.5	B3	0.46	B	0.66	B	0.5	B3
bhincp	0.03	B	0.15	B	0.5	B	0.04	B
bhcap	100,167.	A	43,500.	A	2,363,700.	A	107,500.	A
smtage 1	0.05	J	1.	A2	0.04	A2	0.05	J
smtage2	0.9	J	--	A2	--	A2	0.9	J
smtage3	0.05	J	--	A2	--	A2	0.05	J
inbsmsv	0.5	A2	0.6	A2	0.6	B	0.5	A2
adtrecv	0.4105	F	0.115	F	0.1128	F	0.2485	F
sadrecv	0.048	F	0.025	F	0.058	F	0.023	F
ocnlhar	--	B2	--	D	0.03081	D	--	B2
ocnlrvh	--	B2	0.00138	D	0.01631	D	--	B2
ocnlsuv	1.	B2	0.98646	D	0.94491	D	1.	B2
ocn2har	--	B2	0.00279	D	0.22679	D	--	B2
ocn2rvh	--	B2	0.16822	D	0.13467	D	--	B2
ocn2suv	1.	B2	0.36203	D	0.60055	D	1.	B2
ocn3har	--	B2	0.00321	D	0.28733	D	--	B2
ocn3rvh	--	B2	0.35411	D	0.36056	D	--	B2
ocn3suv	1.	B2	0.00578	D	0.26433	D	1.	B2
ocn4har	--	B2	--	D	0.39795	D	--	B2
ocn4rvh	--	B2	0.55556	D	0.50608	D	--	B2
ocnlsbe	--	B2	0.01216	D	0.00797	D	--	B2
ocn2sbe	0.	B2	0.46696	D	0.03798	D	0.	B2
ocn3sbe	0.	B2	0.63689	D	0.08777	D	0.	B2
ocn4sbe	--	B2	0.4444	D	0.09597	D	--	B2
termhar	--	A	--	A	--	A	--	A
suptermh	0.4	A	0.56	A	0.33	A	0.23	A
msurv	0.5828	E	0.36537	E	0.33874	E	0.4368	E
passcv	0.036889	E	0.32003	E	0.145575	E	0.194627	E
jackspn	1.	A	--	A	--	A	1.	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	JOHN DAY		JOHN DAY		L. WHITE SALMON		L. WHITE SALMON	
	Spring Chinook Natural Value	Spring Chinook Natural source*	Summer Steelhead Natural Value	Summer Steelhead Natural Source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Spring Chinook Hatchery Value	Spring Chinook Hatchery source*
ffem	0.657802	B	0.5	J	0.558364	B	0.55	A
prspsv	0.8	B	0.95	B	0.9	B	0.9	B
egfem	4,733.	B	4,784.	B	4,300.	B	4,300.	A
hatrem	0.		0.		0.		701.	C1
hatsmolt	0.		0.		0.		1,459,066.	C
hintsv	0.5	B	0.5	B3	0.5	B	0.5	B
bhincp	0.158	B	0.027	B	0.123	B	.	
bhcap	279,000.	A	518,581.	A	32,350.	A	836,116.	A
smtagel	1.	A	--	J	1.	A2	_	
smtage2	--	A	0.617	J	--	A2	--	
smtage3	--	A	0.383	J	--	A2	--	
inbsmsv	0.5	A2	0.5	A2	0.5	A2	--	
adtrecv	0.114	F	0.7207	F	0.018	F	0.0059	F
sadtrecv	NS	F	NS	F	0.0504	F	--	F
ocnlhar	0.0018	D	--	B2	--	D	--	D
ocnlrvh	0.09883	D	--	B2	0.00138	D	0.00138	D
ocnlsuv	0.77242	D	1.	B2	0.98646	D	0.98646	D
ocn2har	0.00466	D	--	B2	0.00279	D	0.00279	D
ocn2rvh	0.37788	D	--	B2	0.16822	D	0.16822	D
ocn2suv	0.11589	D	1.	B2	0.36203	D	0.36203	D
ocn3har	0.00787	D	--	B2	0.00321	D	0.00321	D
ocn3rvh	0.4287	D	--	B2	0.35411	D	0.35411	D
ocn3suv	0.04637	D	1.	B2	0.00578	D	0.00578	D
ocn4har	0.07547	D	--	B2	--	D	--	D
ocn4rvh	0.49057	D	--	B2	0.55556	D	0.55556	D
ocnlsbe	0.12695	D	--	B2	0.01216	D	0.01216	D
ocn2sbe	0.50157	D	0.	B2	0.46696	D	0.46696	D
ocn3sbe	0.51706	D	0.	B2	0.63689	D	0.63689	D
ocn4sbe	0.43 396	D	--	B2	0.4444	D	0.4444	D
termhar	0.01	A	0.15	A	--	A	0.084	A
suptermh	--	A	--	A	0.084	A	_	A
msurv	0.56858	E	0.60478	E	0.85081	E	0.68065	E
passcv	0.142005	E	0.109043	E	0.046198	E	0.046198	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	L. WHITE SALMON		L. WHITE SALMON		WHITE SALMON		WHITE SALMON	
	Fall Chinook Natural Value	Fall Chinook Natural source*	Fall Chinook Hatchery Value	Fall Chinook Hatchery source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Spring Chinook Hatchery Value	Spring Chinook Hatchery source*
ffem	0.451515	B	0.447	A	0.558364	B	0.55278	B
prspsv	0.9	B	0.9	B	0.9	B	0.9	B
egfem	4,503.	B	4,503.	A	4,300.	B	4,300.	B
hatrem	0.		1,398.	C1	0.		92.	C1
hatsmolt	0.		1,438,372.	C	0.		175,000.	C
hintsv	0.5	B	0.5	B	0.5	B	0.5	B
bhincp	0.213	B	.		0.158	B		
bhcap	73,652.	A	1,546,819.	A	45,307.	A	--	
smtage1	0.1	A2	--		1.	A2	--	
smtage2	--	A2	--		--	A2	--	
smtage3	--	A2	--		--	A2	--	
inbsmsv	0.5	A2	--		0.5	A2	--	
adtrecv	0.042	F	0.0403	F	0.0145	F	0.0025	F
sadtrecv	0.348	F	--	F	0.053	F	--	F
ocn1har	0.03081	D	0.03081	D	--	D	--	D
ocnlrvh	0.01631	D	0.01631	D	0.00138	D	0.00138	D
ocnlsuv	0.94491	D	0.94491	D	0.98646	D	0.98646	D
ocn2har	0.22679	D	0.22679	D	0.00279	D	0.00279	D
ocn2rvh	0.13467	D	0.13467	D	0.16822	D	0.16822	D
ocn2suv	0.60055	D	0.60055	D	0.36203	D	0.36203	D
ocn3har	0.28733	D	0.28733	D	0.00321	D	0.00321	D
ocn3rvh	0.36056	D	0.36056	D	0.35411	D	0.35411	D
ocn3suv	0.26433	D	0.26433	D	0.00578	D	0.00578	D
ocn4har	0.39795	D	0.39795	D	--	D	--	D
ocn4rvh	0.50608	D	0.50608	D	0.55556	D	0.55556	D
ocnlsbe	0.00797	D	0.00797	D	0.01216	D	0.01216	D
ocn2sbe	0.03798	D	0.03798	D	0.46696	D	0.46696	D
ocn3sbe	0.08777	D	0.08777	D	0.63689	D	0.63689	D
ocn4sbe	0.09597	D	0.09597	D	0.4444	D	0.4444	D
termhar	--	A	0.026	A	--	A	--	A
suptermh	0.026	A	--	A	--	A	--	A
msurv	0.79913	E	0.6393	E	0.80559	E	0.64448	E
passcv	0.093426	E	0.093425	E	0.079336	E	0.079336	E
jackspn	--	A	--	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	WHITE SALMON		WHITE SALMON		KLICKITAT		KLICKITAT	
	Summer Steelhead Natural Value	Summer Steelhead Natural source*	Summer Steelhead Hatchery Value	Summer Steelhead Hatchery source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Spring Chinook Hatchery Value	Spring Chinook Hatchery source*
ffem	0.519	A	0.503	A	0.533	B	0.488738	A
prspsv	0.9	B	0.9	B	0.5	B	0.8	B
egfem	4,170.	A	4,170.	A	4,310.	B	4,188.	A
hatrem	19.	Cl	0.	Cl	67.	Cl	531.	Cl
hatsmolt	33,044.	A	9,828.	C	99,300.	C	783,200.	C
hintsv	0.67	B	0.67	B	0.46	B	0.46	B
bhincp	0.025	B			0.2086	B		
bhcap	1,771.	A	--		620,000.	A	--	
smtage1	--	J	--		1.	A2	--	
smtage2	1.	J	--		--	A2	--	
smtage3	--	J	--		--	A2	--	
inbsmsv	0.5	A2	--		0.5	A2	--	
adtrecv	0.31	F	0.777	F	0.029	F	0.0163	F
sadtrecv	0.1733	F	--	F	0.0268	F	--	F
ocnlhar	--	B2	--	D	--	D	--	D
ocnlrvh	--	B2	0.1519	D	0.00138	D	0.00138	D
ocnlsuv	1.	B2	0.51899	D	0.98646	D	0.98646	D
ocn2har	--	B2	0.0122	D	0.00279	D	0.00279	D
ocn2rvh	--	B2	0.34756	D	0.16822	D	0.16822	D
ocn2suv	1.	B2	--	D	0.36203	D	0.36203	D
ocn3har	--	B2	--	D	0.00321	D	0.00321	D
ocn3rvh	--	B2	--	D	0.35411	D	0.35411	D
ocn3suv	1.	B2	--	D	0.00578	D	0.00578	D
ocn4har	--	B2	--	D	--	D	--	D
ocn4rvh	--	B2	--	D	0.55556	D	0.55556	D
ocnlsbe	--	B2	0.32911	D	0.01216	D	0.01216	D
ocn2sbe	0.	B2	0.64024	D	0.46696	D	0.46696	D
ocn3sbe	0.	B2	--	D	0.63689	D	0.63689	D
ocn4sbe	--	B2	--	D	0.4444	D	0.4444	D
termhar	--	A	0.7	A	0.4477	A	0.4477	A
suptermh	0.7	A	--	A	0.4477	A	--	A
msurv	0.85823	E	0.68658	E	0.8022	E	0.596	E
passcv	0.042177	E	0.042177	E	0.052146	E	0.10983	E
jackspn	1.	A	--	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	KLICKITAT		HOOD		HOOD		HOOD	
	Summer Steelhead Natural Value	Summer Steelhead Natural source*	Spring Chinook Natural Value	Spring Chinook Natural source*	Fall Chinook Natural Value	Fall Chinook Natural source*	Summer Steelhead Natural Value	Summer Steelhead Natural Source*
ffem	0.55	A	0.584348	B	0.422273	B	0.6	B
prspsv	0.9	B	0.9	A2	0.9	A2	0.9	A2
egfem	3,668.	A	4,300.	A	4,500.	A	3,500.	A
hatrem	0.	Cl	0.	Cl	0.		0.	Cl
hatsmolt	50,038.	C	197,988.	C	0.		81,795.	C
hintsv	0.7	B	0.5	B	0.5	B3	0.5	B
bhincp	0.0403	B	0.065	B	0.4686	B	0.025 1	B
bhcap	95,437.	A	24,000.	A	46,000.	A	32,000.	A
smtage1	--	A	1.	A2	0.1	A2	0.05	J1
smtage2	0.94	A	--	A2	--	A2	0.9	J1
smtage3	0.06	A	--	A2	--	A2	0.05	J1
inbsmsv	0.5	A2	0.5	A2	0.5	A2	0.5	A2
adtrecv	0.404	F	0.052	F	0.066	F	0.733	F
sadtrecv	0.0344	F	0.0131	F	NS	F	0.098	F
ocnlhar	--	B2	--	D	0.03998	D	--	B2
ocnlrvh	—	B2	0.00138	D	0.0285	D	—	B2
ocnlsuv	1.	B2	0.98646	D	0.91268	D	1.	B2
ocn2har	--	B2	0.00279	D	0.35933	D	--	B2
ocn2rvh	--	B2	0.16822	D	0.24903	D	--	B2
ocn2suv	1.	B2	0.36203	D	0.30856	D	1.	B2
ocn3har	--	B2	0.00321	D	0.29433	D	--	B2
ocn3rvh	--	B2	0.35411	D	0.44884	D	--	B2
ocn3suv	1.	B2	0.00578	D	0.13902	D	1.	B2
ocn4har	--	B2	--	D	0.39672	D	--	B2
ocn4rvh	--	B2	0.55556	D	0.55	D	--	B2
ocnlsbe	--	B2	0.01216	D	0.01884	D	--	B2
ocn2sbe	0.	B2	0.46696	D	0.08308	D	0.	B2
ocn3sbe	0.	B2	0.63689	D	0.11782	D	0.	B2
ocn4sbe	--	B2	0.4444	D	0.05328	D	1.	B2
termhar	--	A	--	A	0.2	A	--	A
suptermh	0.25	A	0.2	A	0.2	A	0.7	A
msurv	0.78993	E	0.87375	E	0.75 144	E	0.85823	E
passcv	0.064845	E	0.025657	E	0.065404	E	0.042177	E
jackspn	1.	A	--	A	--	A	1.	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	WIND Spring Chinook Natural Value	Spring Chinook Natural source*	WIND Spring Chinook Hatchery Value	Spring Chinook Hatchery source*	WIND Summer steelhead Natural Value	Summer Steelhead Natural Source*	WIND Summer Steelhead Hatchery Value	Summer steelhead Hatchery Source*
ffem	0.558539	B	0.533	A	0.519	A	0.503	A
prspsv	0.9	B	0.9	B	0.9	B	0.9	B
egfem	4,300.	B	4,300.	A	4,138.	A	4,073.	A
hatrem	0.		1,020.	Cl	0.		0.	Cl
hatsmolt	0.		2,105,281.	C	0.		20,125.	C
hintsv	0.5	B	0.5	B3	0.67	B	0.67	B3
bhincp	0.1557	B			0.0341	B		
bhcap	157,533.	A	--		23,498.	A	--	
smtagel	1.	A2	--		0.05	J	--	
smtage2	--	A2	--		0.9	J	--	
smtage3	--	A2	--		0.05	J	--	
inbsmsv	0.5	A2	--		0.5	A2	--	
adtrecv	0.0165	F	0.0074	F	0.136	F	0.1027	F
sadtrecv	0.0097	F	--	F	0.0162	F	--	F
ocnlhar	--	D	--	D	--	B2	--	D
ocnlrvh	0.00138	D	0.00138	D	--	B2	0.1519	D
ocnlsuv	0.98646	D	0.98646	D	1.	B2	0.51899	D
ocn2har	0.00279	D	0.00279	D	--	B2	0.0122	D
ocn2rvh	0.16822	D	0.16822	D	--	B2	0.34756	D
ocn2suv	0.36203	D	0.36203	D	1.	B2	--	D
ocn3har	0.00321	D	0.00321	D	--	B2	--	D
ocn3rvh	0.35411	D	0.35411	D	--	B2	--	D
ocn3suv	0.00578	D	0.00578	D	1.	B2	--	D
ocn4har	--	D	--	D	--	B2	--	D
ocn4rvh	0.55556	D	0.55556	D	--	B2,	--	D
ocnlsbe	0.01216	D	0.01216	D	--	B2	0.32911	D
ocn2sbe	0.46696	D	0.46696	D	0.	B2	0.64024	D
ocn3sbe	0.63689	D	0.63689	D	0.	B2	--	D
ocn4sbe	0.4444	D	0.4444	D	--	B2	--	D
termhar	0.2	A	0.2	A	--	A	0.7	A
suptermh	0.2	A	--	A	0.7	A	--	A
msurv	0.88735	E	0.69853	E	0.88843	E	0.70255	E
passcv	0.028467	E	0.044767	E	0.02904	E	0.040182	E
jackspn	--	A	--	A	1.	A	--	A

TABLE C.1
Base-Case Propagation Parameters

PARAMETER	WENATCHEE		WENATCHEE		WENATCHEE		ENTIAT-R. REACH	
	Spring Chinook Natural Value	Spring Chinook Natural Source*	spring Chinook Hatchery Value	Spring Chinook Hatchery source*	Summer Chinook Natural Value	Summer Chinook Natural Source*	Spring Chinook Natural Value	Spring Chinook Natural Source*
ffem	0.56	H	0.56	H	0.46	H	0.586	A
prspsv	0.75	B	0.75	B	0.526	B	0.72	B
egfem	4,600.	G	4,600.	G	5,240.	G	4,600.	G
hatrem	358.	Cl	1,199.	Cl	490.	Cl	360.	Cl
hatsmolt	672,000.	C	2,250,000.	C	864,000.	C	800,000.	C
hintsv	0.083333	G	0.083333	G	0.516926	H	0.038462	G
bhincp	0.23	B	0.23	B	0.5	B	0.23	B
bhcap	1,200,000.	B	--	B	2,960,504.	B	176,000.	B
smtagel	1.	H	1.	H	0.05	H	1.	H
smtage2	--	H	--	H	--	H	--	H
smtage3	--	H	--	H	--	H	--	H
inbsmsv	0.5	G	0.5	G	0.5	G	0.5	G
adtrecv	0.0761	F	0.2985	F	0.443	F	0.211	F
sadtrecv	NS	F	--	F	NS	F	0.123	F
ocnlhar	0.023	D	0.023	D	0.059	D	0.023	D
ocnlrvh	0.07	D	0.07	D	0.024	D	0.07	D
ocnlsuv	0.897	D	0.897	D	0.873	D	0.897	D
ocn2har	0.041	D	0.041	D	0.352	D	0.041	D
ocn2rvh	0.135	D	0.135	D	0.137	D	0.135	D
ocn2suv	0.454	D	0.454	D	0.456	D	0.454	D
ocn3har	0.04	D	0.04	D	0.388	D	0.04	D
ocn3rvh	0.152	D	0.152	D	0.301	D	0.152	D
ocn3suv	--	D	--	D	0.111	D	--	D
ocn4har	--	D	--	D	0.549	D	--	D
ocn4rvh	--	D	--	D	0.451	D	--	D
ocnlsbe	0.01	D	0.01	D	0.043	D	0.01	D
ocn2sbe	0.369	D	0.369	D	0.055	D	0.369	D
ocn3sbe	0.808	D	0.808	D	0.096	D	0.808	D
ocn4sbe	--	D	--	D	--	D	--	D .
termhar	--	A	0.1	A	--	A	--	A
suptermh	--	A	0.1	A	--	A	--	A
msurv	0.27808	E	0.22246	E	0.07925	E	0.2222	E
passcv	0.13316	E	0.13316	E	0.4146	E	0.146	E
jackspn	--	A	1.	A	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	ENTIAT-R. REACH		ENTIAT-R. REACH		ENTIAT-R. REACH		METHOW	
	Sum/Fall Chinook Natural Value	Sum/Fall Chinook Natural source*	Summer Chinook Natural Value	Summer Chinook Natural source*	Fall Chinook Hatchery Value	Fall Chinook Hatchery source*	Spring Chinook Natural Value	Spring Chinook Natural source*
ffem	0.30184	H	1.		1.		0.7	A
prspsv	0.7	B	1.		1.		0.7	B
egfem	5,240.	G	1.		1.		4,337.	A
hatrem	0.	Cl	1,064.	Cl	0.	Cl	491.	Cl
hatsmolt	0.		1,690,000.	C	200,000.	C	800,000.	C
hintsv	0.400004	H	0.400004	H	0.400004	H	0.1	G
bhincp	.				.		0.1707	A
bhcap	--		--	--	--		826,539.	A
smtagel	--	H	0.05	--	--		1.	H
smtage2	--	H	--				--	H
smtage3	--	H	--				--	H
inbsmsv	1.	G	0.5	—	1.		0.5	G
adtrecv	0.044627	F	0.225	k	0.044627	k	0.0858	F
sadtrecv	NS	F	NS		0.3		0.086	F
ocnlhar	0.0588	D	0.059	l	0.058	l	0.023	D
ocnlrvh	0.0323	D	0.024	I	0.065	l	0.07	D
ocnlsuv	0.87	D	0.873	l	0.856	l	0.897	D
ocn2har	0.3676	D	0.352	l	0.432	I	0.041	D
ocn2rvh	0.1628	D	0.137	l	0.268	l	0.135	D
ocn2suv	0.4191	D	0.456	l	0.266	l	0.454	D
ocn3har	0.397	D	0.388	l	0.435	l	0.04	D
ocn3rvh	0.329	D	0.301	l	0.445	l	0.152	D
ocn3suv	0.1016	D	0.111	l	0.063	l	--	D
ocn4har	0.5167	D	0.549	l	0.384	l	--	D
ocn4rvh	0.4833	D	0.451	l	0.616	l	--	D
ocnlsbe	0.0389	D	0.043	l	0.021	l	0.01	D
ocn2sbe	0.0504	D	0.055	l	0.033	l	0.369	D
ocn3sbe	0.0883	D	0.096	l	0.057	l	0.808	D
ocn4sbe	--	D	--	l	--	l	--	D
termhar	--	A	--	A		A	--	A
supermh	--	A		A	--	A	--	A
msurv	0.19317	E	0.09999	E	0.19317	E	0.2152	E
passcv	0.2342	E	0.2163	E	0.2342	E	0.134	E
jackspn	--	A	--		--		--	A

TABLE C.l
Base-Case Propagation Parameters

PARAMETER	METHOW		OKANOGAN	
	Summer Chinook Natural Value	Summer Chinook Natural source*	Summer Chinook Natural Value	Summer Chinook Natural source*
ffem	0.46	J	0.46	H
prspsv	0.333	B	0.333	B
egfem	5,240.	G	5,240.	G
hatrem	226.	Cl	326.	Cl
hatsmolt	400,000.	C	576,000.	C
hintsv	0.387694	H	0.484618	H
bhincp	0.3 162	B	0.3 162	B
bhcap	**1,470,822.**	B	**1,435,704.**	B
smtage1	0.05	H	0.05	H
smtage2	--	H	--	H
smtage3	--	H	--	H
inbsmsv	0.5	G	0.5	G
adtrecv	1.027	F	0.984	F
sadtrecv	NS	F	NS	F
ocnlhar	0.059	D	0.059	D
ocnlrvh	0.024	D	0.024	D
ocnlsuv	0.873	D	0.873	D
ocn2har	0.352	D	0.352	D
ocn2rvh	0.137	D	0.137	D
ocn2suv	0.456	D	0.456	D
ocn3har	0.388	D	0.388	D
ocn3rvh	0.301	D	0.301	D
ocn3suv	0.111	D	0.111	D
ocn4har	0.549	D	0.549	D
ocn4rvh	0.451	D	0.451	D
ocnlsbe	0.043	D	0.043	D
ocn2sbe	0.055	D	0.055	D
ocn3sbe	0.096	D	0.096	D
ocn4sbe	--	D	--	D
termhar	--	A	--	A
suptermh	--	A	--	A
msurv	0.04984	E	0.04984	E
passcv	0.478	E	0.478	E
jackspn	--	A	--	A

TABLE C.l
Base-Case Propagation Parameters

Parameter	Description
ffem	fraction female
prspsv	prespawning survival
egfem	mean eggs per female
hatrem	adult take by hatchery
hatsmolt	hatchery fry released
hintsv	post-release survival
bhiucp	Bcverton-Holt intercept
bhcap	Beverton-Holt carrying capacity
smtagel	yearling migrants (O-l)
smtage2	yearling migrants (l-2)
smtage3	yearling migrants (2-3)
inbsmsv	inbasin overwinter survival
adtrecv	fraction recovered as adults
sadtrecv	C.V. of adult recovery
ocnlhar	1 st year ocean harvest
ocnlrvh	1 st year river harvest
ocnlsuv	fraction recovered in years 2+
ocn2har	2nd year ocean harvest
ocn2rvh	2nd year river harvest
ocn2suv	fraction recovered in years 3+
ocn3 har	3rd year ocean survival
ocn3rvh	3rd year river harvest
ocn3suv	fraction recovered in year 4
ocn4har	4th year ocean harvest
ocn4rvh	4th year river harvest
ocnlsbe	1st year subbasin escapement
ocn2sbe	2nd year " "
ocn3sbe	3rd year " "
ocn4sbe	4th year " "
termhar	terminal harvest rate for natural fish
suptermh	terminal harvest rate for supplementation fish
msurv	mean mainstem survival rate
passcv	C.V. of mainstem survival
jackspn	If 0, jacks do not contribute to spawning population

TABLE C.l
Base-Case Propagation Parameters

*Sources of Data:

A	**Subbasin** Plans
Al	Calculated from data in **Subbasin** Plans
A2	Based on **Subbasin** Plans for a different **subbasin**
B	System Planning Model Parameter Files (NPPC)
B1	Parameter calculated from age specific data
B2	Parameter estimated from age specific return **data;** assumes that ocean and **inriver** harvest is zero
B3	Parameter taken from a different stock
C	Fish Passage Center 1990 Hatchery Data/ WA State Dept. of Fisheries 1990 Hatchery Program data
C1	Brood needs for **hatsmolt** calculated based on fraction female, eggs per female, and egg-smolt survival
D	Estimated from Coded Wire Tag data (Pacific States Marine Fisheries Commission. Unpublished Document)
E	Estimated from **CRiSP** output
F	Internal Calculation based on estimates of **fish** abundance.
F1	Internal Calculation based on hatchery release and assumed smolt-adult survival.
G	**Mullan** 1990
H	**Mullan** 1987
I	estimated from run data in **Mullan** 1987
J	Howell et al. 1985
J1	Based on data from Howell et al. 1985 for a different stock
NS	No supplementation in base case or in actions

TABLE C.2
Calibration Data

SUBBASIN	Stock Type	Calib. Spawn	Calib. Escape	Calib. Runsize	Calib. Hattake	Calib. Hatsmlt	Calib. Sbbarv	Calib. Hrvrate	Calib. Adtrecv
GRANDE RONDE									
Spring Chinook	Nat	1,080	1.736	2,215	183		45	0.03	0.0825
Spring Chinook	**Supp**	220	443	565	37	294,358	11	0.03	0.0085
Steelhead	Nat	11,027	8,857	8,857	702			0.00	0.1292
Steelhead	**Supp**	4,271	6,222	6,222	290	**1,555,204**	593	0.10	0.0170
CLEARWATER									
Spring Chinook	Nat	2,747	2,534	3,233	**992**		86	0.04	0.0143
Spring Chinook	**Supp**	1,687	**4,031**	5,142	609	**1,464,375**	137	0.04	0.0083
Steelhead	Nat	10,262	9,195	9,195	536			0.00	0.0495
Steelhead	**Supp**	3,111	10,001	10,001	279	**1,122,846**	5,833	0.60	0.03 14
LOWER SALMON									
Spring Chinook	Nat	25	49	62				0.00	0.0405
Spring Chinook	**Supp**							0.00	NS
Steelhead	Nat	4,309	1.148	1,148	307			0.00	0.1340
Steelhead	**Supp**	3,441	4,546	4,546	245	629.541		0.00	0.0237
LITTLE SALMON									
Spring Chinook	Nat	387	103	132	217			0.00	0.0088
Spring Chinook	**Supp**	345	867	1,106	194	250.000		0.00	0.0255
Steelhead	Nat	3,116	2.103	2,103	393			0.00	0.1370
Steelhead	**Supp**	**1,526**	5,047	**5,047**	306	699.317	2.862	0.60	0.0236
MID MAIN SALMON									
Spring Chinook	Nat	86	167	213				0.00	0.0378
Spring Chinook	**Supp**							0.00	NS
Steelhead	Nat	1,797	2.25 1	2.25 1	5			0.00	0.1540
Steelhead	**Supp**							0.00	NS
MID FORK SALMON									
Spring Chinook	Nat	674	1,313	1,675				0.00	0.0326
Spring Chinook	**Supp**							0.00	0.0185
LEMHI									
Spring Chinook	Nat	112	219	279				0.00	0.0386
Spring Chinook	**Supp**							0.00	0.0185
Steelhead	Nat	944	1,186	1,186	5			0.00	0.1540
Steelhead	**Supp**							0.00	0.0328
UPPER SALMON									
Spring Chinook	Nat	1.424	749	956	457			0.00	0.0129
Spring Chinook	**Supp**	1,093	2,480	3,164	351	715,400		0.00	0.0255
Summer Chinook	**Nat**	95	206	241				0.00	0.0340
Summer Chinook	Supp							0.00	NS
Steelhead	Nat	18,734	7,526	7,526	1,333			0.00	0.1324
Steelhead	**Supp**	13,037	17,224	17,224	928	**2,386,652**		0.00	0.0246
S. FORK SALMON									
Summer Chinook	Nat	238	516	603				0.00	0.0511
Summer Chinook	**Supp**							0.00	NS
Steelhead	Nat	990	1.242	1,242	**5**			0.00	0.0500
Steelhead	**Supp**							0.00	NS

TABLE C.2
Calibration Data

SUBBASIN	Stock Type	Calib. Spawn	Calib Escape	Calib. Runsize	Calib. Hattake	Calib. Hatsmlt	Calib. Sbharv	Calib. Hrvrate	Calib. Adtrecv
PANTHER CREEK									
Summer Chinook	Nat	4	8	9				0.00	0.0403
Summer Chinook	SUPP							0.00	0.0173
Steelhead	Nat	118	153	153	5			0.00	0.1500
Steelhead	SUPP							0.00	NS
PAHSIMEROI									
Summer Chinook	Nat	13	28	33				0.00	0.0314
Summer Chinook	SUPP							0.00	NS
Steelhead	Nat	2.960	363	363	284			0.00	0.1310
Steelhead	SUPP	2.690	3.620	3,620	258	501,600		0.00	NS
TUCANNON									
Spring Chinook	Nat	202	391	500				0.00	0.0780
Spring Chinook	SUPP							0.00	0.0575
Steelhead	Nat	603	755	755	2			0.00	0.2530
Steelhead	SUPP							0.00	0.2800
IMNAHA									
Spring Chinook	Nat	482	839	1,071	73			0.00	0.1190
Spring Chinook	SUPP	52	102	128	8	100.000		0.00	0.0074
DESCHUTES									
Spring Chinook	Nat	1,555	5,050	9,026	61		1,464	0.29	0.2660
Spring Chinook	SUPP							0.00	NS
Fall Chinook	Nat	3.619	5,875	54,348			1,763	0.30	0.0976
Fall Chinook	SUPP							0.00	NS
Steelhead	Nat	6,210	8,441	8,441	8		1,245	0.15	0.1628
Steelhead	SUPP							0.00	NS
WALLA WALLA									
Spring Chinook	Nat	546	1,412	2,510				0.00	0.3978
Spring Chinook	SUPP							0.00	0.0730
Steelhead	Nat	3,862	4,828	4,828				0.00	0.4105
Steelhead	SUPP							0.00	0.0480
UMATILLA									
Spring Chinook	Nat	222	451	644				0.00	0.1150
Spring Chinook	SUPP							0.00	0.0255
Fall Chinook	Nat	2,772	5,986	55,381				0.00	0.1128
Fall Chinook	SUPP							0.00	0.0580
Steelhead	Nat	1.857	2,082	2.082	32			0.00	0.2485
Steelhead	SUPP	214	301	301	4	60,000	30	0.10	0.0230
JOHN DAY									
Spring Chinook	Nat	2,552	4.161	7,398			42	0.01	0.1140
Spring Chinook	SUPP							0.00	NS
Steelhead	Nat	28,862	35,143	35,743			5,361	0.15	0.7207
Steelhead	SUPP							0.00	NS
L. WHITE SALMON									
Spring Chinook	Nat	44	50	71				0.00	0.0180
Spring Chinook	SUPP							0.00	0.0504
Fall Chinook	Nat	42	50	461				0.00	0.0420
Fall Chinook	SUPP							0.00	0.3480

TABLE C.2
Calibration Data

SUBBASIN	Stock Type	Calib. Spawn	Calib. Escape	Calib. Runsize	Calib. Hattake	Calib. Hatsmlt	Calib. Sbbarv	Calib. Hrvrate	Calib. Adtrecv
WHITE SALMON									
Spring Chinook	Nat	45	50	72				0.00	0.0145
Spring Chinook	SUPP							0.00	0.0530
Steelhead	Nat	447	110	110	8			0.00	0.3100
Steelhead	SUPP	349	1,300	1,300	7	13,044	**905**	0.70	0.1733
KLICKITAT									
Spring Chinook	Nat	91	334	478			150	0.45	0.0290
Spring Chinook	SUPP							0.00	0.0268
Steelhead	Nat	2,993	5,305	5,305			2,902	0.55	0.4040
Steelhead	SUPP	830	2,035	2.035		107,000	1,113	0.55	0.0344
HOOD									
Spring Chinook	Nat	123	174	249			35	0.20	0.0520
Spring Chinook	SUPP							0.00	0.0131
Fall Chinook	Nat	122	198	1,521			40	0.20	0.0660
Fall Chinook	SUPP							0.00	NS
Steelhead	Nat	1,997	3,956	3,956			2,769	0.70	0.7330
Steelhead	SUPP	929	3,440	3,440		81.795	2.408	0.70	0.0980
WIND									
Spring Chinook	Nat	151	213	304			43	0.20	0.0165
Spring Chinook	SUPP							0.00	0.0097
Steelhead	Nat	334	371	371				0.00	0.1360
Steelhead	Supp							0.00	0.0162
ENTIAT									
Spring Chinook	Nat	1,847	2,400	3,576	360			0.00	0.2110
Spring Chinook	SUPP	352	565	842	69	800,000		0.00	0.1230
METHOW									
Spring Chinook	Nat	2,503	3,127	4,661	491			0.00	0.0858
Spring Chinook	SUPP	603	993	1,481	118	800,000		0.00	0.0860
Summer Chinook	Nat	1,188	4,798	27,954				0.00	1.0270
Summer Chinook	SUPP							0.00	1.0270
OKANOGON									
Summer Chinook	Nat	1.033	4,172	24,308				0.00	0.9840
Summer Chinook	SUPP							0.00	0.9840
WENATCHEE									
Spring Chinook	Nat	4,268	5,777	8,611				0.00	0.0761
Spring Chinook	SUPP							0.00	0.0761
Summer Chinook	Nat	4,346	11,111	64,742				0.00	0.4430
Summer Chinook	SUPP							0.00	0.4430

The sum of natural and supplementation fish spawning in streams equals natural apawners.

The sum of natural and supplementation fish taken for broodstock equals HATTAKE.

Hatchery take is calculated as the number of fish needed to provide broodstock for plant,
   i.e., Hatchery take = Hatchery plant / (fraction female * eggs per female * egg-smolt survival).

A hatchery plant is considered "hatchery production" if (1) the release is on site, or (2) It appears that the
   intention of management is for the released fish to return to the hatchery racks

A hatchery plant is considered supplementation if (1) release is off site, such as from an acclimation pond,
   or (2) it appears that management's intent is for the released fiih to return to natural spawning grounds

NS: No supplementation in base case or in actions

TABLE C.3
Base Case Data

SUBBASIN	Stock Type	Base Escape	Base Runsize	Base Hattake	Base Hatsmlt	Base Sbharv	Base Harvrate	Base Adtrecv
GRANDE RONDE								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
CLEARWATER								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
LOWER SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
LITTLE SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
MID MAIN SALMON					**SEE NOTES**			
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
MID FORK SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
LEMHI								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
UPPER SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Summer Chinook	Nat							
Summer Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
S. FORK SALMON								
Summer Chinook	Nat							
Summer Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							

TABLE C.3
Base Case Data

SUBBASIN	Stock Type	Base Escape	Base Runsize	Base Hattake	Base Hatsmlt	Base Sbharv	Base Harvrate	Base Adtrecv
PANTHER CREEK								
Summer Chinook	Nat							
Summer Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
PAHSIMEROI								
Summer Chinook	Nat							
Summer Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
TUCANNON								
Spring Chinook	Nat	1,106	959	1,223	72		0.00	o.oooo
Spring Chinook	SUPP	629	1,266	1,615	41	145,146	0.00	o.oooo
Steelhead	Nat							
Steelhead	SUPP							
IMNAHA								
Spring Chinook	Nat	606	970	1.237	327		0.00	o.oooo
Spring Chinook	SUPP	191	447	570	103	444,462	0.00	o.oooo
DESCHUTES								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Fall Chinook	Nat							
Fall Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
WALLA WALLA								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat	6,059	5,234	5,234			0.00	o.oooo
Steelhead	SUPP	1,872	3,899	3,899		278,762	1560.00	0.4000
UMATILLA								
Spring Chinook	Nat	1,889	733	1,045	818		0.00	o.oooo
Spring Chinook	SUPP	1,425	5,109	7,286	715	1,700,000	2460.00	0.5600
Fall Chinook*	Nat	8,179	7,986	73,888	3,404		0.00	o.oooo
Fall Chinook	SUPP	3,693	9,810	90,769	1,876	7.000,OOO	2618.00	0.3300
Steelhead	Nat	2,441	2,245	2,245	129		0.00	o.oooo
Steelhead	SUPP	712	1.202	1.202	45	239,193	266.00	0.2300
JOHN DAY								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
L. WHITE SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Fall Chinook	Nat							
Fall Chinook	SUPP							

TABLE C.3
Base Case Data

SUBBASIN	Stock Type	Base Escape	Base Runsize	Base Hattake	Base Hatsmlt	Base Sbharv	Base Harvrate	Base Adtrecv
WHITE SALMON								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat	986	114	114	19		0.00	0.0000
Steelhead	SUPP	884	3,293	3,293	18	33,044	2292.00	0.7000
KLICKITAT								
Spring Chinook	Nat	602	1.605	**2,289**	67		701.00	0.4500
Spring Chinook	SUPP	181	689	**982**	20	**99,300**	301.00	0.4500
Steelhead	Nat	6,237	6,216	6,216			**0.00**	**0.0000**
Steelhead	SUPP	642	952	952		50,038	238.00	0.2500
HOOD								
Spring Chinook	Nat	850	326	465			0.00	0.0000
Spring Chinook	SUPP	562	**794**	1,133		197,988	159.00	0.2000
Fall Chinook	Nat							
Fall Chinook	SUPP							
Steelhead	Nat	5.075	4,607	4.607			0.00	0.0000
Steelhead	SUPP	**929**	3.440	3,440		81,795	2408.00	0.7000
WIND								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Steelhead	Nat							
Steelhead	SUPP							
ENTIAT								
Spring Chinook	Nat							
Spring Chinook	SUPP							
METHOW								
Spring Chinook	Nat							
Spring Chinook	SUPP							
Summer Chinook	Nat	1,777	6,040	35,189	226		0.00	o.oooo
Summer Chinook	SUPP	327	1,362	7,938	42	**400,000**	0.00	0.0000
OKANOOON								
Summer Chinook	Nat	2,006	6,076	35,402	326		0.00	o.oooo
Summer Chinook	SUPP	**559**	2,350	13,689	91	576.000	0.00	0.0000
WENATCHEE								
Spring Chinook	Nat	**4,729**	5,965	8,890	358		0.00	o.oooo
Spring Chinook	SUPP	556	**795**	1.185	42	672,000	0.00	o.oooo
Summer Chinook	Nat	5,587	12,081	70,388	**490**		0.00	0.0000
Summer Chinook	SUPP	1,018	2,691	15,679	109	864,000	0.00	o.oooo

Base case data are not entered if the values are the same as in the Calibration case in Table C.2

* Prespawning survival different than in calibration case for Umatilla Fall Chinook

The sum of natural and supplementation fish spawning in streams equals natural apawners.

The sum of natural and supplementation fish taken for broodstock equals HATTAKE.

Hatchery take equals the number of fish needed to provide broodstock for planting (Hatchery take = Hatchery plant / (fraction female * eggs per female * egg-smolt survival); parameters are specific for hatchery stock.

A hatchery plant is considered "hatchery production" if (1) the release is on site, or (2) It appears that the intention of management is for the released fish to return to the hatchery racks

A hatchery plant is considered "supplementation" if (1) The release is off site, such as from an acclimation pond, or (2) It appears that the intention of management is for the released fish to return to natural spawning grounds

NS: No supplementation in base case or actions

TABLE D.1
Effects of Propagation Actions

Subbasin	Description of action	Subbasin Plans Action #	post-rel surv	pre-sp surv	basin surv	egg-sm suw
GRANDE RONDE						
Spring Chinook	improve hatchery effectiveness	1.2	1.275	1.000	1.000	1.000
Spring Chinook	improve habitat	1.3	1.000	0.994	0.994	1.016
Spring Chinook	supplementation**	2.4	1.000	1.000	1.000	1.000
Summer Steelhead	improve hatchery effectiveness	1.2	1.500	1.000	1.000	1.000
Summer Steelhead	improve habitat	1.3	1.000	1.000	0.995	1.266
Summer Steelhead	supplementation**	2.4	1.000	1.000	1.000	1.000
CLEARWATER						
Spring Chinook	hatchery production**	1.1. 1.2	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	1.6	1.000	1.000	**1.000**	1.000
Spring Chinook	hatchery production**	1.12.3.29	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	1.16	**1.000**	1.000	1.000	1.000
Spring Chinook	improve habitat (also steelhead 1.1)	**2.22, 3.28**	1.000	1.000	1.000	1.000
Spring Chinook	improve habitat; acquire land	**3.26, 3.27**	1.000	1.000	1.000	1.000
Spring Chinook	remove barriers	4.34	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	5.35	1.000	1.000	1.000	1.000
Summer Steelhead	improve habitat	1.1.2.22	1.000	1.000	1.000	1,000
Summer Steelhead	improve habitat; acquire land	2.20	1.000	1.000	1.000	1.000
Summer Steelhead	remove barriers	**2.24, 3.28**	1.000	1.000	1.000	1.000
Summer Steelhead	improve hatchery effectiveness	2.30	1.642	1.000	1.000	1.000
LOWER SALMON						
Spring Chinook	hatchery production**	3.7	1.000	1.000	1.000	1.000
Summer Steelhead	hatchery production**	3.5	1.000	1.000	1 . 0	1.000
LITTLE SALMON						
Spring Chinook	enhance habitat; remove barriers	3.7.3.8	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.9	1.000	1.000	1.000	1.000
Summer Steelhead	improve habitat; remove barriers	3.7,3.8	1.000	1.000	1.000	1.000
Summer Steelhead	supplementation**	3.9	1.000	1.000	1.000	1.000
MID MAIN SALMON						
Spring Chinook	hatchery production**	2.2	1.000	1.000	1.000	1.000
Summer Steelhead	hatchery production**	2.2	1.000	1.000	1.000	1.000
MID FORK SALMON						
Spring Chinook	supplementation**	2.7	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.9	1.000	1.000	1.000	1.000
LFMHI						
Spring Chinook	supplementation**	3.4	1.000	1.000	1.000	1.000
Summer Steelhead	supplementation**	3.4	1.000	1.000	1.000	1.000
UPPER SALMON						
Spring Chinook	improve habitat	2.9	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.11,3.12	1.000	1.000	1.000	1.000
Summer Chinook	hatchery production**	3.8	1.000	1.000	1.000	1.000
Summer Steelhead	improve habitat	2.8	1.000	1.000	1.000	1.000
Summer Steelhead	hatchery production**	3.10	1.000	1.000	1.000	1.000
S. FORK SALMON						
Summer Chinook	improve habitat	1.1	1.000	1.000	1.000	1.333
Summer Chinook	hatchery production**	3.7	1.000	1.000	1.000	1.000
Summer Steelhead	improve habitat	1.1	1.000	1.000	1.000	1.267
Summer Steelhead	hatchery production**	3.4	1.000	1.000	1.000	1.000

TABLE D.l
Effects of Propagation Actions

Subbasin	Description of action	smolt cap	hatch take	batch plant	gen sens	gen risk
GRANDE RONDE						
Spring Chinook	improve hatchery effectiveness	1.000			c/d	low
Spring Chinook	improve habitat	1.133			c/d	low
Spring Chinook	supplementation**	1.000	1,248	2,000,000	c / d	med
Summer Steelhead	improve hatchery effectiveness	1.000			c/d	low
Summer Steelhcad	improve habitat	1.219			c/d	low
Summer Steclhead	supplementation**	1.000	505	1,000,000	c / d	med
CLEARWATER						
Spring Chinook	hatchery production**	1.000	694	664,758	c/d	med
Spring Chinook	supplementation**	1.000	560	826,800	c/d	med
Spring Chinook	hatchery production**	1.000	228	277.459	c/d	med
Spring Chinook	supplementation**	1.000	1.016	1,500,000	c / d	med
Spring Chinook	improve habitat (also steelhead 1.1)	1.012			c/d	low
Spring Chinook	improve habitat; acquire land	1.033			c/d	low
Spring Chinook	remove barriers	1.045			c/d	low
Spring Chinook	supplementation**	1.000	677	1,000,000	c / d	med
Summer Steelhead	improve habitat	1.004			a/b/c/d	low
Summer Steelhead	improve habitat; acquire land	1.009			a/h/c/d	low
Summer Steelhead	remove barriers	1.047			a/b/c/d	low
Summer Steelhead	improve hatchery effectiveness	1.000			a/b/c/d	low
LOWER SALMON						
Spring Chinook	hatchery production**	1.000	894	1,000,000	a / h	high
Summer Steelhead	hatchery production**	1.000	623	1,300,000	a/b/c/d	med
LI'ITLE SALMON						
Spring Chinook	enhance habitat; remove barriers	1.124			c/d	low
Spring Chinook	supplementation**	1.000	871	1,000,000	c / d	med
Summer Steelhead	improve habitat; remove barriers	1.045			c/d	low
Summer Steelhead	supplementation**	1.000	444	800,000	c/d	med
MID MAIN SALMON						
Spring Chinook	hatchery production**	1.000	815	1,000,000	a / b	high
Summer Steelhead	hatchery production**	1.000	404	1,000,000	a / h	high
MID FORK SALMON						
Spring Chinook	supplementation**	1.000	347	500,000	a/b	high
Spring Chinook	supplementation**	1.000	347	500,000	a / b	high
LEMHI						
Spring Chinook	supplementation**	1.000	815	1,000,000	a / b	high
Summer Steelhead	supplementation**	1.000	470	1,000,000	c / d	med
UPPER SALMON						
Spring Chinook	improve habitat	1.005			c/d	low
Spring Chinook	supplementation**	1.000	1,792	2,800,000	c / d	med
Summer Chinook	hatchery production**	1.000	622	1,000,000	a / b	high
Summer Steelhead	improve habitat	1.005			c/d	low
Summer Steelhead	hatchery production**	1.000	1,391	2.500.000	c/d	med
S. FORK SALMON						
Summer Chinook	improve habitat	1.117			c/d	low
Summer Chinook	hatchery production**	1.000	963	1,000,000	c / d	med
Summer Steelhead	improve habitat	1.042			a h	low
Summer Steelhead	hatchery production**	1.000	228	500,000	a / b	high

TABLE D.l
Effixts of Propagation Actions

Subbasln	Description of action	Subbasin Plans Action #	post-rel surv	pre-sp suw	basin surv	egg-sm surv
PANTHER CREEK						
Summer Chinook	supplementation**	2.3	1.000	1.000	1.000	1.000
Summer Chinook	trap and haul program	3.4	1.000	**0.968**	1.000	1.841
Summer Chinook	design/implement restoration	4.5	1.000	1.000	1.000	2.080
Summer Steelhead	hatchery production**	2.3	1.000	1.000	1.000	1.000
Summer Steelhead	trap and haul program	3.5	1.000	0.985	1.000	1.408
Summer Steelhead	design/implement restoration	4.6	1.000	1.000	1.000	1.520
PAHSIMEROI						
Summer Chinook	hatchery production**	3.6	1.000	1.000	1.000	1.000
Summer Steelhead	hatchery production**	3.6	1.000	1.000	1.000	1.000
TUCANNON						
Spring Chinook	improve habitat	1.1	1.000	1.000	1.000	1.350
Spring Chinook	improve passage at Starbuck	1.2	1.000	1.250	1.000	1.000
Summer Steelhead	improve habitat	1.2, 1.3, 1.4	1.000	1.000	1.000	1.150
Summer Steelhead	improve habitat	**2.5, 2.6**	1.000	1.000	1.000	1.610
Summer Steelhead	trap natural broodstock	3.7	1.056	1.000	1.000	1.000
IMNAHA						
Spring Chinook	supplementation**	3.2	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.2	1.000	1.000	1.000	1.000
DESCHUTES						
Spring Chinook	improve habitat	1.1, 1.2	1.000	1.250	1.003	1.380
Spring Chinook	provide passage at W. River Falls	2.3	1.000	1.000	**0.984**	0.990
Spring Chinook	hatchery production**	1.4	1.000	1.000	1.000	1.000
Spring Chinook	hatchery production**	1.5	1.000	1.000	1.000	1.000
Spring Chinook						
Fall Chinook	improve habitat--part 1	1.1, 1.4	1.000	1.000	1.000	1.017
Fall Chinook	improve habitat--part 2	2.2, 1.4	1.000	1.000	1.000	1.307
Fall Chinook	improve habitat--part 3	3.3, 1.4	1.000	1.000	1.000	1.474
Summer Steelhead	improve habitat	1.4, 1.5	1.000	1.032	1.078	1.125
Summer Steelhead	provide passage at W. River Falls	3.6	1.000	1.001	0.998	**0.972**
Summer Steelhead	improve habitat	**2.2, 2.3**	1.000	1.008	1.014	**1.000**
Summer Steelhead	hatchery production**	5.7	1.000	1.000	1.000	1.000
WALLA WALLA						
Spring Chinook	supplementation**; improve passage	I.A	1.000	1.500	1.188	1.000
Spring Chinook	supplementation**; improve habitat	I.B	1.000	1.000	1.000	1.312
Spring Chinook	supplementation**	**III.B**	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**; enhance flow	**II.B**	1.000	1.200	1.053	1.000
Spring Chinook	supplementation**	**III.C**	1.000	1.000	1.000	1.000
Summer Steelhead	improve adult and juvenile passage	**I.A**	1.000	1.125	1.188	1.000
Summer Steelhead	improve habitat	**I.B**	**1.000**	**1.000**	**1.000**	1.333
Summer Steelhead	enhance flows	**II.B**	**1.000**	**1.000**	**1.053**	1.000
Summer Steelhead	supplementation**	**III.C**	1.000	1.000	1.000	1.000

TABLE D.l
Effects of Propagation Actions

Subbasin	Description of action	smolt CaP	hatch take	hatch gen plant	sens	en risk
PANTHER CREEK						
Summer Chinook	supplementation**	1.000	622	1,000,000	a/b	high
Summer Chinook	trap and haul program	4.525			a/b	low
Summer Chinook	design/implement restoration	11.025			a/b	low
Summer Steelhead	hatchery production**	1.000	365	700,000	a/b	high
Summer Steelhead	trap and haul program	4.752			a/b	low
Summer Steelhead	design/implement restoration	12.976			a/b	low
PAHSIMEROI						
Summer Chinook	hatchery production**	1.000	657	1.000.000	c/d	med
Summer Steelbead	hatchery production**	1.000	389	700,000	c/d	med
TUCANNON						
Spring Chinook	improve habitat	1.000			a/b	low
Spring Chinook	improve passage at Starbuck	1.000			a/b	low
Summer Steelhead	improve habitat	1.000			c/d	low
Summer Steelhead	improve habitat	1.000			cld	low
Summer Steelhead	trap natural broodstock	1.000			c/d	low
IMNAHA						
Spring Chinook	supplementation**	1.000	506	688,000	c/d	med
Spring Chinook	supplenwnation**	1.000	716	972,000	c/d	med
DESCHUTES						
Spring Chinook	improve habitat	1.181			c/d	low
Spring Chinook	provide passage at W. River Falls	1.392			cld	low
Spring Chinook	hatchery production**	1.000	222	350,000	c/d	med
Spring Chinook	hatchery production**	1.000	317	500.000	c/d	med
Spring Chinook						
Fall Chinook	improve habitat--part 1	1.028			a/b	low
Fall Chinook	improve habitat--part 2	1.206			a/b	low
Fall Chinook	improve habitat--part 3	1.559			a/b	low
Summer Steelhead	improve habitat	1.385			c/d	low
Summer Steelhead	provide passage at W. River Falls	1.153			c/d	low
Summer Steelhead	improve habitat	1.143			c/d	low
Summer Steelhead	hatchery production**	1.000	50	100,000	c/d	med
WALLA WALLA						
Spring Chinook	supplementation**; improve passage	1.000			elf	low
Spring Chinook	supplementation**; improve habitat	1.682			e/f	low
Spring Chinook	supplementation**	1.000	67	100,000	e/f	low
Spring Chinook	supplementation**; enhance flow	1.000			elf	low
Spring Chinook	supplementation**	1.000	336	500,000	e/f	low
Summer Steelhead	improve adult and juvenile passage	1.000			c/d	low
Summer Steelhead	improve habitat	1.443			cld	low
Summer Steelhead	enhance flows	1.021			cld	low
Summer Steelhead	supplementation**	1.000	73	100,000	c / d	med

TABLE D.1
Effects of Propagation Actions

Subbasin	Description of action	Subbasin Plans Action #	post-rel surv	pre-sp surv	basin surv	egg-sm s u w
UMATILLA						
Spring Chinook	improve adult and juvenile passage	I.A	1.000	1.500	1.203	1.000
Spring Chinook	improve habitat	I.B	1.000	1.000	1.000	1.400
Spring Chinook	enhance flow	II.A	1.000	1.200	1.053	1.000
Spring Chinook	supplementation**	IILB	1.000	1.000	1.000	1.000
Spring Chinook	provide headwater storage	II.B	1.000	1.056	1.000	1.143
Fall Chinook	improve adult and juvenile passage	I.A	1.000	1.500	1.900	1.000
Fall Chinook	improve habitat	I.B	1.000	1.000	1.000	1.027
Fall Chinook	enhance flow	II.A	1.000	1.200	1.053	1.000
Fall Chinook	provide headwater storage	II.B	1.000	1.056	1.000	1.000
Fall Chinook						
Summer Steelhead	improve adult and juvenile passage	LA	1.000	1.125	1.203	1.000
Summer Steelhead	improve habitat	LB	1.000	1.000	1.000	0.926
Summer Steelhead	enhance flow	II.A	1.000	1.056	1.053	1.000
Summer Steelhead	provide headwater storage	II.B	1.000	1.000	1.000	1.000
JOHN DAY						
Spring Chinook	improve habitat	1.1.1.2.2.3	1.000	1.068	1.000	1.259
Spring Chinook	screen diversions	1.5	1.000	1.000	1.000	1.095
Spring Chinook						
Summer Steelhead	improve habitat	1.1	1.000	1.000	1.000	1.407
Summer Steelhead	provide adult passage	2.2	1.000	1.000	1.000	1.030
L. WHITE SALMON						
Spring Chinook	supplementation**	1.1	1.000	1.000	1.000	1.000
Spring Chinook	hatchery production**	2.2	1.000	1.000	1.000	1.000
Fall Chinook	supplementation**	1.1	1.000	1.000	1.000	1.000
Fall Chinook	hatchery production**	2.2	1.000	1.000	1.000	1.000
WHITE SALMON						
Spring Chinook	remove barrier at Condit dam	1.1, 1.3	1.000	1.000	1.000	1.000
Spring Chinook	remove barrier; screen diversions	1.2, 1.1, 1.3	1.000	1.000	1.000	1.266
Spring Chinook	remove barriers at Condit and RM16.3	2.4, 1.1, 1.3	1.000	1.000	1.000	1.000
Spring Chinook	screen diversions; remove barriers	1.1,2,3; 2.4,:	1.000	1.000	1.000	1.266
Spring Chinook	supplementation**	3.6	1.000	1.000	1.000	1.000
Spring Chinook	hatchery production**	4.7	1.000	1.000	1.000	1.000
Summer Steelhead	enhance habitat	1.1	1.000	1.000	1.000	1.100
Summer Steelhead	supplementation**	2.3	1.060	1.000	1.000	1.000
Summer Steelhead	hatchery production** using net pens	3.4	1.000	1.000	1.000	1.000
KLICKITAT						
Spring Chinook	remove barrier at Castile Falls	2.3	1.000	1.000	1.000	1.000
Spring Chinook	redesign ladder at Klickitat Hatchery	2.4	1.000	1.600	1.000	1.091
Spring Chinook	improve habitat	3.5.3.6	1.000	1.000	1.000	1.143
Spring Chinook	supplementation**	1.2	1.543	1.000	1.000	1.000
Summer Steelhead	improve habitat	3.4, 3.5	1.000	1.000	1.000	1.241
Summer Steelhead	remove barrier at Castile Falls	2.3	1.000	1.000	1.000	1.000
Slimmer Steelhcdd	remove barrier at W. Fork Falls	2.3	1.000	1.000	1.000	1.000
Summer Steelhead	remove barrier at L. Klickitat Falls	2.3	1.000	1.000	1.000	1.000

TABLE D.l
Effects of Propagation Actions

Subbasin	Description of action	smolt cap	hatch take	hatch gen p l a u t	sens	gen risk
UMATILLA						
Spring Chinook	improve adult and juvenile passage	1.000			cld	low
Spring Chinook	improve habitat	1.977			c/d	low
Spring Chinook	enhance flow	1.000			c/d	low
Spring Chinook	supplementation**	1.000	403	600,000	c/d	med
Spring Chinook	provide headwater storage	1.215			c/d	low
Fall Chinook	improve adult and juvenile passage	1.000			c/d	low
Fall Chinook	improve habitat	1.091			c/d	low
Fall Chinook	enhance flow	1.000			cld	low
Fall Chinook	provide headwater storage	1.000			c/d	low
Fall Chinook						
Summer Steelhead	improve adult and juvenile passage	1.000			c/d	low
Summer Steelhead	improve habitat	1.577			c/d	low
Summer Steelhead	enhance flow	1.000			c/d	low
Summer Steelhead	provide headwater storage	1.112			c/d	low
JOHN DAY						
Spring Chinook	improve habitat	1.207			a/b	low
Spring Chinook	screen diversions	1.000			a/b	low
Spring Chinook						
Summer Steelhead	improve habitat	1.265			a/b	low
Summer Steelhead	provide adult passage	1.165			a/b	low
L. WHITE SALMON						
Spring Chinook	supplementation**	1.000	58	130,000	e/f	low
Spring Chinook	hatchery production**	1.000	317	660,000	elf	low
Fall Chinook	supplementation**	1.000	104	150.000	e/f	low
Fall Chinook	hatchery production**	1.000	3.500	3,600,000	e / f	low
WHITE SALMON						
Spring Chinook	remove barrier at Condit dam	3.258			cld	low
Spring Chinook	remove barrier; screen diversions	3.258			c/d	low
Spring Chinook	remove barriers at Condit and RM16.3	6.318			c/d	low
Spring Chinook	screen diversions; remove barriers	6.318			c/d	low
Spring Chinook	supplementation**	1.000	235	500,000	c/d	med
Spring Chinook	hatchery production**	1.000	105	200.000	c/d	med
Summer Steelhead	enhance habitat	1.000			c/d	low
Summer Steelhead	supplementation**	1.000	16	27,000	c/d	med
Summer Steelhead	hatchery production** using net pens	1.000		27.000	c/d	med
KLICKITAT						
Spring Chinook	remove barrier at Castile Falls	1.582			c/d	low
Spring Chinook	redesign ladder at Klickitat Hatchery	1.000			c/d	low
Spring Chinook	improve habitat	1.000			c/d	low
Spring Chinook	supplementation**	1.000	1,628	2,400,000	c / d	med
Summer Steelhead	improve habitat	1.000			c/d	low
Summer Steelhead	remove barrier at Castile Falls	1.149			c/d	low
Summer Steelhead	remove barrier at W. Fork Falls	1.027			c/d	low
Summer Steelheacl	remove barrier at L. Klickitat Falls	1.009			c/d	low

TABLE D.l
Effects of Propagation Actions

Subbasin	Description of action	Subbasin Plans Action #	post-rel surv	pre-sp surv	basin surv	egg-sm surv
HOOD						
Spring Chinook	supplement with non-native stock	1.1	1.000	1.000	1.000	1.000
Spring Chinook	supplement with native stock	2.2	1.000	1.000	1.000	1.000
Fall Chinook	install bypass; screen diversions	1.3	1.000	1.000	1.049	1.067
Summer Steelhead	install bypass; screen diversions	1.5	1.000	1.000	1.022	1.020
Summer Steelhead	supplement with non-native stock	1.1	1.000	1.000	1.000	1.000
Summer Steelhead	remove barriers	2.6	1.000	1.003	1.000	1.000
Summer Steelhead	improve habitat	3.7	1.000	1.000	1.000	1.000
WIND	supplement with native stock	4.2	1.000	1.000	1.000	1.000
Spring Chinook	improve habitat	1.1	1.000	1.000	1.000	1.100
Spring Chinook	redesign Trout Creek Dam	1.2	1.000	1.022	1.022	1.000
Spring Chinook	augmentation facility; WRN well	2.3, 2.4	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.6, 3.7, 3.8	1.500	1.000	1.000	1.000
Spring Chinook	hatchery production**	4.9	1.000	1.000	1.000	1.000
Spring Chinook	improve habitat	2.5	1.000	1.000	1.000	1.004
Summer Steelhead	improve habitat	1.1	1.000	1.000	1.000	1.100
Summer Steelhead	redesign Trout Creek Dam	1.2	1.000	1.022	1.022	1.000
Summer Steelhead	augmentation facility; WRN well	2.3, 2.4	1.000	1.000	1.000	1.000
Summer Steelhead	supplementation**	3.6, 3.7, 3.8	1.119	1.000	1.000	1.000
Summer Steelhead	improve habitat	2.5	1.000	1.000	1.000	1.005
Summer Steelhead	hatchery production**	4.9, 4.10	1.060	1.000	1.000	1.000
ENTIAT						
Spring Chinook	screen diversions	1.1	1.000	1.000	1.130	1.000
Spring Chinook	decrease poaching	1.2	1.000	1.100	1.000	1.000
Spring Chinook	passage at Box Canyon	2.3	1.000	1.000	1.000	1.000
Spring Chinook	spawning channel	2.4	1.000	1.000	1.000	1.000
Spring Chinook	supplementation**	3.5	1.000	1.000	1.000	1.000
METHOW						
Spring Chinook	improve habitat	1.1	1.000	1.000	1.000	1.100
Spring Chinook	screen diversions	1.2	1.000	1.000	1.120	1.000
Spring Chinook	water acquisition	2.3	1.000	1.000	1.000	1.000
Spring Chinook	groundwater channels	2.4	1.000	1.000	1.000	1.200
Spring Chinook	supplementation**	4.7	1.000	1.000	1.000	1.000
Spring Chinook	hatchery improvements	4.8	1.100	1.000	1.000	1.000
Summer Chinook	improve habitat	1.1	1.000	1.000	1.000	1.100
Summer Chinook	screen diversions	1.2	1.000	1.000	1.120	1.000
OKANOGAN						
Summer Chinook	improve habitat	1.1	1.000	1.000	1.000	1.100
Summer Chinook	screen diversions	1.2	1.000	1.000	1.120	1.000
Summer Chinook	water acquisition	2.3	1.000	1.000	1.000	1.000
Summer Chinook	adult passage at Enloe dam	3.6	1.000	1.000	1.000	1.000
WENATCHEE						
Spring Chinook	upstream passage at Dryden dam	1.1	1.000	1.020	1.000	1.000
Spring Chinook	screen diversions	1.2	1.000	1.000	1.050	1.000
Spring Chinook	decrease poaching	1.3	1.000	1.030	1.000	1.000
Spring Chinook	improve habitat	2.4	1.000	1.020	1.000	1.130
Spring Chinook	improve habitat	4.5	1.000	1.000	1.000	1.000
Spring Chinook	hatchery improvements	5.7	1.400	1.000	1.000	1.000
Summer Chinook	upstream passage at Dryden dam	1.1	1.000	1.130	1.000	1.000
Summer Chinook	screen diversions	1.2	1.000	1.000	1.200	1.000

TABLE D.l
Effects of Propagation Actions

Subbasin	Description of action	smolt cap	hatch take	hatch plant	gen sens	gen risk
HOOD						
Spring Chinook	supplement with non-native stock	1.000		275,000	a/b	high
Spring Chinook	supplement with native stock	1.000	158	275,000	ah	high
Fall Chinook	install bypass; screen diversions	1.000			a/b	low
Summer Steelhead	install bypass; screen diversions	1.000			c/d	low
Summer Steelhead	supplement with non-native stock	1.000		90,000	c/d	med
Summer Steelhead	remove barriers	1.000			c/d	low
Summer Steelhead	improve habitat	1.024			c/d	low
WIND	supplement with native stock	1.000	56	90,000	c/d	med
Spring Chinook	improve habitat	1.000			c/d	low
Spring Chinook	redesign Trout Creek Dam	1.000			c/d	low
Spring Chinook	augmentation facility; WRN well	1.092			c/d	low
Spring Chinook	supplementation**	1.000	484	1,000,000	c / d	med
Spring Chinook	hatchery production**	1.000	872	1.800.000	c/d	med
Spring Chinook	improve habitat	1.000			c/d	low
Summer Steelhead	improve habitat	1.000			c/d	low
Summer Steelhead	redesign Trout Creek Dam	1.000			c/d	
Summer Steelhead	augmentation facility; WRN well	1.100			c/d	
Summer Steelhead	supplementation**	1.000	21	40,000	c/d	med
Summer Steelhead	improve habitat	1.000			c/d	low
Summer Steelhead	hatchery production**	1.000		75,000	c/d	med
ENTIAT						
Spring Chinook	screen diversions	1.000			c/d	low
Spring Chinook	decrease poaching	1.000			c/d	low
Spring Chinook	passage at Box Canyon	1.010			c/d	low
Spring Chinook	spawning channel	1.130			c/d	low
Spring Chinook	supplementation**	1.000	90	200,000	c/d	med
METHOW						
Spring Chinook	improve habitat	1.000			c/d	low
Spring Chinook	screen diversions	1.000			c/d	low
Spring Chinook	water acquisition	1.050			c/d	low
Spring Chinook	groundwater channels	1.060			c/d	low
Spring Chinook	supplementation**	1.000	193	413,813	c/d	med
Spring Chinook	hatchery improvements	1.000			c/d	low
Summer Chinook	improve habitat	1.000			c/d	low
Summer Chinook	screen diversions	1.000			c/d	low
OKANOGAN						
Summer Chinook	improve habitat	1.000			c/d	low
Summer Chinook	screen diversions	1.000			c/d	low
Summer Chinook	water acquisition	1.200			cld	low
Summer Chinook	adult passage at Enloe dam	2.040			c/d	low
WENATCHEE						
Spring Chinook	upstream passage at Dryden dam	1.000			c/d	low
Spring Chinook	screen diversions	1.000			c/d	low
Spring Chinook	decrease poaching	1.000			c/d	low
Spring Chinook	improve habitat	1.000			c/d	low
Spring Chinook	improve habitat	1.090			c/d	low
Spring Chinook	hatchery improvements	1.000			c/d	low
Summer Chinook	upstream passage at Dryden dam	1.000			a/b	low
Summer Chinook	screen diversions	1.000			a/b	low

TABLE D.l
Effects of Propagation Actions

*Actions are based on "Columbia Basin System Planning Salmon and Steelhead Production Plans (Columbia Basin Fish and Wildlife Authority, 1990).

**A hatchery plant is considered "hatchery production" if:
   (1) The release is on site,
   (2) It appears that the intention of management is for the released fish to return to the hatchery racks,
  A hatchery plant is considered "supplementation" if:
   (1) The release is off site, such as from an acclimation pond,
   (2) It appears that management's intent is for the released fish to return to natural spawning grounds

Parameter definitions:
   post-rel surv: post-release survival for hatchery fish
   pre-sp surv: pre-spawning survival for adult returns
   basin surv: overwintering survival of Pre-smolts in the subbasin
   egg-sm surv: egg to presmolt survival in the subbasin
   smolt cap: smolt capacity of habitst in subbasin
   hatch take: number of fish taken for broodstock
   hatch plant: number of hatchery fish planted
   gen sens: genetic sensitivity of action (see note 4 below)
   gen risk: genetic risk of action (see note 4 below)

Notes on Biological Effects:
   (1) Biological effects on survivals and smolt capacity expressed as a multiplier on base parameter values
      (i.e., 1 + proportional increase in parameter value).
   (2) Combinations of actions produce parameter changes that are the product of the individual actions'
      effects, for parameters post-rel surv, pre-sp SUN, basin surv, egg-sm surv, and smolt cap
   (3) Combinations of actions produce parameter changes that are the sum of the individual action's
      effects, for parameters hatch take and hatch plant
   (4) Calculation of Genetic Risk
      Genetic sensitivity taken from Table 61 (CBFWA, 1991b) and SPM data 1990.
      gen risk = low if hatch plant = 0, or if hatch plant > 0 and gen sens = e/f
      gen risk = med if hatch plant > 0 and gen sens = c/d
      gen risk = high if hatch plant > 0 and gen sens = a/b
   (5) Hatchery take is calculated as the number of fish needed to provide broodstock for plant,
      (i.e., Hatchery take = Hatchery plant / (fraction female * eggs per female * egg-smolt survival),
      where these parameters are specific for the hatchery stock)

TABLE D.2
Costs of Propagation Actions

Subbasin	Description of action*	Subbasin Plans Action #	Capital cost	O & M cost	Annualized Cost**
GRANDE RONDE					
Spring Chinook	improve hatchery effectiveness	1.2	0	250,000	250,000
Spring Chinook	improve habitat	1.3	2,853,600	88,000	198,907
Spring Chinook	supplementation***	2.4	3,066,667	333,333	452,521
Summer Steelhead	improve hatchery effectiveness	1.2	0	250,000	250,000
Summer Steelhead	improve habitat	1.3	16,186,800	500,000	1,129,108
Summer Steelhead	supplementation* * *	2.4	4,600,000	500,000	678,781
CLEARWATER					
Spring Chinook	hatchery production* * *	1.1, 1.2	313,056	34,028	46,195
Spring Chinook	supplementation* * *	1.6	633,880	68,900	93,536
Spring Chinook	hatchery production***	1.12, 3.29	265,139	28,819	39,124
Spring Chinook	supplementation***	1.16	1,916,667	208,333	282,826
Spring Chinook	improve habitat (also steelhead 1.1)	2.22, 3.28	145,000	15,500	21,135
Spring Chinook	improve habitat; acquire land	3.26, 3.27	3,357,000	23,000	153,471
Spring Chinook	remove barriers	4.34	137,500	0	5,344
Spring Chinook	supplementation***	5.35	1,380,000	150,000	203,634
Summer Steelhead	improve habitat	1.1, 2.22	145,000	15,500	21,135
Summer Steelhead	improve habitat; acquire land	2.20	3,357,000	23,000	153,471
Summer Steelhead	remove barriers	2.24, 3.28	137,500	0	5,344
Summer Steelbead	improve hatchery effectiveness	2.30	0	250,000	250,000
LOWER SALMON					
Spring Chinook	hatchery production***	3.7	1,277,778	138,889	188,550
Summer Steelhead	hatchery production***	3.5	5,980,000	650,000	882,416
LITTLE SALMON					
Spring Chinook	enhance habitat; remove barriers	3.7, 3.8	1,585,926	14,212	75,850
Spring Chinook	supplementation***	3.9	1,277,778	138,889	188,550
Summer Steelhead	improve habitat; remove barriers	3.7, 3.8	1,585,926	14,212	75,850
Summer Steelhead	supplementation***	3.9	3,680,000	400,000	543,025
MID MAIN SALMON					
Spring Chinook	hatchery production***	2.2	1,277,778	138,889	188,550
Summer Steelhead	hatchery production***	2.2	4,600,000	500,000	678,781
MID FORK SALMON					
Spring Chinook	supplementation* **	2.7	638,889	69,444	94,275
Spring Chinook	supplementation***	3.9	638,889	69,444	94,275
LEMHI					
Spring Chinook	supplementation* * *	3.4	1,277,778	138,889	188,550
Summer Steelhead	**supplementation*****	3.4	4,600,000	500,000	678,781
UPPER SALMON					
Spring Chinook	improve habitat	2.9	150,374	1,900	7,744
Spring Chinook	supplementation***	3.11, 3.12	3,577,778	388,889	527,941
Summer Chinook	hatchery production***	3.8	1,277,778	138,889	188,550
Summer Steelhead	improve habitat	2.8	150,374	1,900	7,744
Summer St&head	hatchery production***	3.10	11,500,000	1,250,000	1,696,953
S. FORK SALMON					
Summer Chinook	improve habitat	1.1	1,017,146	1,330	40,862

TABLE D.2
Costs of Propagation Actions

Subbasin	Description of action*	Subbasin Plans Action #	Capital cost	O & M cost	Annualized cost**
Summer Chinook	hatchery production***	3.7	1,277,778	138,889	188,550
Summer Steelhead	improve habitat	1.1	1,017,146	1,330	40,862
Summer Steelhcad	hatchery production* * *	3.4	2,300,000	250,000	339,391
PANTHER CREEK					
Summer Chinook	supplementation***	2.3	1,277,778	138,889	188,550
Summer Chinook	trap and haul program	3.4	101,500	31,900	35,845
Summer Chinook	design/implement restoration	4.5	6,000,000	200,000	433,193
Summer Steelhead	hatchery production***	2.3	3,220,000	350,000	475,147
Summer Steelhead	trap and haul program	3.5	121,500	31,900	36,622
Summer Steelhead	design/implement restoration	4.6	6,000,000	200,000	433,193
PAHSIMEROI					
Summer Chinook	hatchery production***	3.6	1,277,778	138,889	188,550
Summer Steelhead	hatchery production***	3.6	3,220,000	350,000	475,147
TUCANNON					
Spring Chinook	improve habitat	1.1	131,300	17,160	22,263
Spring Chinook	improve passage at Starbuck	1.2	250,000	10,000	19,716
Summer Steelhead	improve habitat	1.2, 1.3, 1.4	131,300	17,160	22,263
Summer Steelhead	improve habitat	2.5, 2.6	149,051	10,855	16,648
Summer Steelhead	trap natural broodstock	3.7	20,000	10,000	10,777
IMNAHA					
Spring Chinook	supplementation***	3.2	1,582,400	172,000	233,501
Spring Chinook	supplementation***	3.2	2,235,600	243,000	329,888
DESCHUTES					
Spring Chinook	improve habitat	1.1, 1.2	1,864,000	30,400	102,845
Spring Chinook	provide passage at W. River Falls	2.3	2,984,000	62,700	178,675
Spring Chinook	hatchery production***	1.4	805,000	87,500	118,787
Spring Chinook	hatchery production***	1.5	0	125,000	125,000
Spring Chinook					
Fall Chinook	improve habitat--part 1	1.1, 1.4	70,500	26,600	29,340
Fall Chinook	improve habitat--part 2	2.2, 1.4	239,500	41,800	51,108
Fall Chinook	improve habitat--part 3	3.3, 1.4	408,500	57,000	72,877
Summer Steelhead	improve habitat	1.4, 1.5	1,864,000	30,400	102,845
Summer Steelhead	provide passage at W. River Falls	3.6	2,984,000	62,700	178,675
Summer Steelhead	improve habitat	2.2, 2.3	1,202,000	38,000	84,716
Summer Steelhead	hatchery production* * *	5.7	460,000	50,000	67,878
WALLA WALLA					
Spring Chinook	supplementation***; improve passage	I.A	1,475,000	339,000	396,327
Spring Chinook	supplementation***; improve habitat	LB	3,910,000	100,300	252,264
Spring Chinook	supplementation***	III.B	0	35,000	35,000
Spring Chinook	supplementation***; enhancc flow	II.B	200,600,000	235,000	8,031,418
Spring Chinook	supplementation***	III.C	2,500,000	175,000	272,164
Summer Steelhead	improve adult and juvenile passage	I.A	1,475,000	294,000	351,327
Summer Steelhead	improve habitat	LB	3,910,000	65,300	217,264
Summer Steelhead	enhance flows	II.B	200,600,000	200,000	7.996.418
Summer Steelhead	supplementation***	III.C	833,333	41,667	74,055

TABLE D.2
Costs of Propagation Actions

Subbasin	Description of action*	Subbasin Plans Action #	Capital cost	O&M cost	Annualized cost**
UMATILLA					
Spring Chinook	improve adult and juvenile passage	1.A	9,337,000	806,500	1,169,387
Spring Chinook	improve habitat	LB	7,230,000	138,000	418,998
Spring Chinook	enhance flow	1I.A	43,050,000	750,000	2,423,160
Spring Chinook	supplementation***	**III.B**	3,000,000	210,000	326,596
Spring Chinook	provide headwater stage	ILB	78,200,000	66,000	3,105,282
Fall Chinook	improve adult and juvenile passage	1.A	9,337,000	806,500	1,169,387
Fall Chinook	improve habitat	1.B	7,230,000	138,000	418,998
Fall Chinook	enhance flow	**II.A**	**43,050,000**	750,000	**2,423,160**
FalI Chinook	provide headwater storage	**II.B**	**78,200,000**	66,000	**3,105,282**
FaII Chinook					
Summer Steelhead	improve adult and juvenile passage	**I.A**	**9,337,000**	806,500	**1,169,387**
Summer Steelhead	improve habitat	LB	**7,230,000**	138,000	418,998
Summer Steelhead	enhance flow	**II.A**	**43,050,000**	750,000	**2,423,160**
Summer Steelhead	provide headwater storage	**II.B**	**78,200,000**	66,000	**3,105,282**
JOHN DAY					
Spring Chinook	improve habitat	**1.1,1.2,2.3**	**13,416,854**	217,170	738,623
Spring Chinook	screen diversions	1.5	295,480	13,875	25,359
Spring Chinook					
Summer Steelbead	improve habitat	1.1	**13,416,854**	217,170	738,623
Summer Steelhead	provide adult passage	2.2	**1,180,000**	15,000	60,861
L. WHITE SALMON					
Spring Chinook	supplementation***	1.1	29,900	3,250	4,412
Spring Chinook	hatchery production***	2.2	**1,518,000**	165,000	223,998
Fall Chinook	supplementation***	1.1	8,625	938	1,273
Fall Chinook	hatchery production***	2.2	828,000	90,000	122,181
WHITE SALMON					
Spring Chinook	remove barrier at Condit dam	1.1, 1.3	**7,000,000**	50,000	322,058
Spring Chinook	remove barrier; screen diversions	1.2, 1.1, 1.3	**7,250,000**	75,000	356,775
Spring Chinook	remove barriers at Condit and **RM16.3**	2.4, 1.1, 1.3	**8,000,000**	70,000	380,924
Spring Chinook	screen diversions; remove barriers	1.1,2,3; 2.4,	**8,500,000**	120,000	450,357
Spring Chinook	supplementation***	3.6	115,000	12,500	16,970
Spring Chinook	hatchery production***	4.7	**460,000**	50,000	67,878
Summer Steelhead	enhance habitat	1.1	0	30,000	30,000
Summer Steelhead	supplementation* * *	2.3	324,200	33,500	46.100
Summer Steelhead	hatchery production* * * using net pens	3.4	124,200	13,500	18,327
KLICKITAT					
Spring Chinook	remove barrier at Castile Falls	2.3	760,000	8,000	37,538
Spring Chinook	redesign ladder at Klickitat Hatchery	2.4	50,297	0	1,955
Spring Chinook	improve habitat	3.5,3.6	7,074,200	107,420	382,362
Spring Chinook	supplementation* * *	1.2	5,520,000	600,000	814,538
Summer Steelhead	improve habitat	3.4, 3.5	7,074,200	107,420	382,362
Summer SteeIhead	remove barrier at Castile Falls	2.3	760,000	8,000	37,538
Summer Steelhead	remove barrier at W. Fork Falls	2.3	180,000	2,400	9,396
Summer Steelhead	remove barrier at L. Klickitat Falls	2.3	160,000	2,400	8,618

TABLE D.2
Costs of Propagation Actions

Subbasin	Description of action*	Subbasin Plans Action #	Capital Cost	O & M cost	Annualized cost**
HOOD					
Spring Chinook	supplement with non-native stock	1.1	690,000	75,000	101,817
Spring Chinook	supplement with native stock	2.2	690,000	75,000	101,817
Fall Chinook	install bypass; screen diversions	1.3	525,000	48,926	69,330
Summer Steelhead	install bypass; screen diversions	1.5	525,000	48,926	69,330
Summer Steelhead	supplement with non-native stock	1.1	460,000	50,000	67,878
Summer Steelhead	remove barriers	2.6	160,000	0	6,218
Summer Steelhead	improve habitat	3.7	625,356	61,186	85,491
WIND	supplement with native stock	4.2	460,000	50,000	67,878
Spring Chinook	improve habitat	1.1	0	30,000	30,000
Spring Chinook	redesign Trout Creek Dam	1.2	350,000	5,000	18,603
Spring Chinook	augmentation facility; WRN well	2.3, 2.4	10,300,000	120,000	520,315
Spring Chinook	supplementation***	3.6, 3.7, 3.8	4,300,000	260,000	427,122
Spring Chinook	hatchery production***	4.9	4,140,000	450,000	610,903
Spring Chinook	improve habitat	2.5	10,000	2,000	2,389
Summer Steelhead	improve habitat	1.1	0	30,000	30,000
Summer Steelhead	redesign Trout Creek Dam	1.2	350,000	5,000	18,603
Summer Steelhead	augmentation facility; WRN well	2.3, 2.4	10,300,000	120,000	520.3 15
Summer Steelhead	supplementation***	3.6, 3.7, 3.8	496,000	30,000	49,277
Summer Steelhead	improve habitat	2.5	10,000	2,000	2,389
Summer Steelhead	hatchery production* * *	4.9,4.10	207,000	22,500	30,545
ENTIAT					
Spring Chinook	screen diversions	1.1	75,000	15,000	19,307
Spring Chinook	decrease poaching	1.2	40,000	0	1,266
Spring Chinook	passage at Box Canyon	2.3	1,500,000	20,000	78,298
Spring Chinook	spawning channel	2.4	300,000	30,000	55,130
Spring Chinook	supplementation* * *	3.5	46,000	5,000	6,788
METHOW					
Spring Chinook	improve habitat	1.1	40,000	0	1,266
Spring Chinook	screen diversions	1.2	536,470	0	30,808
Spring Chinook	water acquisition	2.3	1,782,500	50,000	119,278
Spring Chinook	groundwater channels	2.4	300,000	10,000	21,660
Spring Chinook	supplementation***	4.7	3,3 10,504	206,907	335,571
Spring Chinook	hatchery improvements	4.8	0	200,000	200,000
Summer Chinook	improve habitat	1.1	40,000	0	1,266
Summer Chinook	screen diversions	1.2	536,470	0	30,808
OKANOGAN					
Summer Chinook	improve habitat	1.1	40,000	0	4,689
Summer Chinook	screen diversions	1.2	536,470	0	30,808
Summer Chinook	water acquisition	2.3	2,800,000	180,000	293,570
Summer Chinook	adult passage at Enloe dam	3.6	160,000	0	5,063

TABLE D.2
Costs of Propagation Actions

Subbasin	Description of action*	Subbasin Plaus Action #	Capital cost	O & M Cost	Annualized cost**
WENATCHEE					
Spring Chinook	upstream passage at Dryden dam	1.1	**1,000,000**	50,000	107,428
Spring Chinook	screen diversions	1.2	100,000	20,000	25,743
Spring Chinook	decrease poaching	1.3	50,000	50,000	51,943
Spring Chinook	improve habitat	2.4	904,800	90,480	196,550
Spring Chinook	improve habitat	4.5	**5,000,000**	50,000	244,327
Spring Chinook	hatchery improvements	5.7	0	200,000	200,000
Summer Chinook	upstream passage at Dryden dam	1.1	1,000,000	50,000	107,428
Summer Chinook	screen diversions	1.2	100,000	20,000	25,743

*Actions are based on "Columbia Basin System Planning Salmon and Steelhead Production Plans (Columbia Basin Fish and Wildlife Authority, 1990).
**Costs are annualized at 3%.
***A hatchery plant is considered "hatchery production" if:
    (1) The release is on site,
    (2) It appears that the intention of management is for the released fish to return to the hatchery racks.
  A hatchery plant is considered "supplementation" if:
    (1) The release is off site, such as from an acclimation pond,
    (2) It appears that the intention of management is for the released fish to return to natural spawning grounds

TABLE E.l
Selected Passage Model (CRiSP.0) Parameters

species	project or pool	fge-caiib. (1)	fge-base (2)	transport survival Xl (3)	travel coeff. X0 (4)	travel coeff. (5)	fracmort (6)
Yearling (#)	Wells	0.80	0.80		0.3169	0.7359	0.0350
	Rocky Reach	0.00	0.70		0.2970	1.0238	0.0350
	Rock Island	0.00	0.70		0.5390	2.2620	0.0350
	Wanapum	0.00	0.70		0.1990	0.6040	0.0350
	Priest Rapids	0.00	0.72		0.4040	0.9160	0.0350
	N. Coniluence				0.5000	0.5390	0.0350
	L. Granite	0.77	0.88	0.573	0.1310	1.1180	
	L. Goose	0.77	0.88	0.573	0.2060	1.7600	
	L. Monumental	0.02	0.73		0.2350	2.1700	
	Ice Harbor	0.51	0.78		0.2830	1.1190	
	S. Confiuence				0.2400	0.5370	
	McNary	0.75	0.90	0.534	0.0900	1.5250	
	John Day	0.72	0.72		0.0500	1.0380	
	The Daiies	0.40	0.63		0.2770	5.6070	
	Bonneville 1	0.76	0.76		0.1770	6.3940	
	Bonneville 2	0.19	0.65				
Subyearling (+)	Wells	0.70	0.70		0.3169	0.7359	0.0350
	Rocky Reach	0.00	0.50		0.2970	1.0238	0.0350
	Rock Island	0.00	0.50		0.5390	2.2620	0.0350
	Wanapum	0.00	0.50		0.1990	0.6040	0.0350
	Priest Rapids	0.00	0.50		0.4040	0.9160	0.0350
	N. Confluence				0.5000	0.5390	0.0350
	L. Granite	0.48	0.60	0.421	o.oooo	5.6200	0.0226
	L. Goose	0.48	0.60	0.421	o.oooo	5.6200	0.0226
	L. Monumental	0.02	0.35		o.oooo	5.6200	0.0226
	Ice Harbor	0.51	0.35		o.oooo	5.6200	0.0226
	S. Confluence				o.oooo	5.6200	0.0226
	McNary	0.40	0.60	0.421	o.oooo	5.6200	0.0226
	John Day	0.30	0.30		o.oooo	5.6200	0.0226
	The Daiies	0.40	0.38		0.0000	5.6200	0.0226
	Bonneville 1	0.30	0.30		o.oooo	5.6200	0.0226
	Bonneville 2	0.24	0.24				
Steeihead	L. Granite	0.79	0.88	0.800	0.1310	1.1180	
	L. Goose	0.79	0.88	0.800	0.2060	1.7600	
	L. Monumental	0.04	0.74		0.2350	2.1700	
	Ice Harbor	0.51	0.92		0.2830	1.1190	
	S. Confluence				0.2400	0.5370	
	McNary	0.75	0.90	0.750	0.0900	1.5250	
	John Day	0.86	0.86		0.0500	1.0380	
	The Daiies	0.40	0.70		0.2770	5.6070	
	Bonneville 1	0.78	0.78		0.1770	6.3940	
	Bonneville 2	0.35	0.50				

TABLE E.1
Selected Passage Model (CRiSP.0) Parameters

species	project or pool	mort X2 coeff. (7)	mort Xl coeff. (8)	mort X0 coeff. (9)	cutoff (10)
Yearling (#)	Wells				
	Rocky Reach				
	Rock Island				
	Wanapum				
	Priest Rapids				
	N. Confluence				
	L. Granite	.000001510	-.000359	0.02390	141
	L. Goose	.00o001510	-.000359	0.02390	141
	L. Monumental	.000001510	-.000359	0.02390	141
	Ice Harbor	.000001510	-.000359	**0.02390**	141
	S. Confiuence	.000001510	-.000359	0.02390	141
	McNary	.000000353	-.000203	0.03179	341
	John Day	.000000353	-.000203	0.03179	341
	The Daiies	.000000353	-.000203	0.03179	341
	Bonneville 1	.000000353	-.000203	0.03179	341
	Bonneviiie 2				
Subyearling (+)	Wells				
	Rocky Reach				
	Rock Island				
	Wanapum				
	Priest Rapids				
	N. Confluence				
	L. Granite				
	L. Goose				
	L. Monumental				
	Ice Harbor				
	S. Confluence				
	McNary				
	John Day				
	The Daiies				
	Bonneville 1				
	Bonneville 2				
Steelhead	L. Granite	.000001510	-.000359	**0.02390**	141
	L. Goose	.000001510	-.000359	**0.02390**	**141**
	L. Monumental	.000001510	-.000359	**0.02390**	141
	Ice Harbor	.000001510	-.000359	0.02390	141
	S. Confluence	.000001510	-.000359	0.02390	141
	McNary	.000000353	-.000203	0.03179	341
	John Day	.000000353	-.000203	0.03179	341
	The Daiies	.000000353	-.000203	0.03179	341
	Bonneville 1	.000000353	-.000203	0.03179	341
	Bonneville 2				

TABLE E.l
Selected Passage Model (CRiSP.0) Parameters

NOTES AND SOURCES OF DATA:

* see **CRiSP.0** documentation for explanation of terms (Hinrichsen, et. al, 1991)

(#) spring chinook and Snake River summer chinook

(+) fall chinook and Columbia River summer chinook

(1) fish guidance efficiency, calibration case (Sherer and Fisher, 1991)

(2) fish guidance efficiency, all other alternatives (Sherer and Fisher, 1991)

(3) transportation survival (Sherer and Fisher, 1991)

(4) Xl coefficient of travel time relationship, with Snake subyearling at 5 km/day (Sherer and Fisher, 1991)

(5) **X0** coefficient of travel tune relationship, with Snake subyearling at 5 km/day (Sherer and Fisher, 1991)

(6) fraction mortality per day for constant mortality relationship (Sherer and Fisher, 1991)

(7) X2 coefficient of reservoir mortality relationship (Sherer and Fisher, 1991)

(8) Xl coefficient of reservoir mortality relationship (Sherer and Fisher, 1991)

(9) **X0** coefficient of reservoir mortality relationship (Sherer and Fisher, 1991)

10) cutoff value (kcfs) above which reservoir survival is constant (Sherer and Fisher, 1991)

TABLE E.2
Entry of Smolts to Mainstem

Subbasin	Stock**	Miles***	1	2	3	4	5	6	7	8	9	10
Grande Ronde	Spr Ch	115						114.7				
	Sihd	115										
Clearwater	Spr Ch	115	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Sthd	115										
Lower Salmon	Spr Ch	115							1.7		5.2	1.7
	Sthd	115										
Little Salmon	Spr Ch	115							1.7		5.2	1.7
	Sthd	115										
Mid Main Salmon	Spr Ch	115							1.7		5.2	1.7
	Sthd	115										
Mid Fork Salmon	Spr Ch	115							1.7		5.2	1.7
Lemhi	Spr Ch	115							1.7		5.2	1.7
	Sthd	115										
Upper Salmon	Spr Ch	115							1.7		5.2	1.7
	Sum Ch	115				2.2	0.6		0.6	0.6	0.6	
	Sthd	115					70.5	70.5	70.5	70.5	70.5	70.5
S. Fork Salmon	Sum Ch	115				2.2	0.6		0.6	0.6	0.6	
	Sthd	115										
Panther Creek	Sum Ch	115				2.2	0.6		0.6	0.6	0.6	
	Sthd	115										
Pahsimeroi	Sum Ch	115				2.2	0.6		0.6	0.6	0.6	
	Sthd	115										
Tucannon	Spr Ch	40										
	Sthd	40										
Jmnaha	Spr Ch	115	124.9	124.9								
Deschutes	Spr Ch	30										
	Fall Ch	30										
	Sthd	30										
Walla Walla	Spr Ch	42										
	Sthd	42										
Umatilla	Spr Ch	121	996									
	Fall Ch	121										
	Sthd	121										4
John Day	Spr Ch	20	50									
	Sthd	20										
L. White Salmon	Spr Ch	34										
	Fall Ch	34										
White Sahnon	Spr Ch	42										
	Sthd	42										
Klickitat	Spr Ch	68										
	Sthd	68										3
Hood	Spr Ch	40										
	Fall Ch	40							5046			
	Sthd	40										
Wind	Spr Ch	25										
	Sthd	25										2
Entiat	Spr Ch	27	30									
Methow	Spr Ch	10										
	Sum Ch	10										
Okanogan	Sum Ch	10										
Wenatchee	Spr Ch	32										
	Sum Ch	32										

TABLE E.2
(continued)

Grande Ronde	Spr Ch*	11	12	13	14	15	16	17	18	19	20	21	22
							Day*						
	Sthd								8.3	8.3	8.3	8.3	8.3
Clearwater	Spr Ch	0.7	0.7	0.7	0.7	0.7	0.7	0.7					
	Sthd						24.9	24.9	24.9	24.9	24.9	24.9	24.9
Lower Salmon	Spr Ch					1.7	1.7	1.7	3.5	1.7		3.5	5.2
	Sthd												
Little Salmon	Spr Ch					1.7	1.7	1.7	3.5	1.7		3.5	5.2
	Sthd												
Mid Main Salmon	Spr Ch					1.7	1.7	1.7	3.5	1.7		3.5	5.2
	Sthd												
Mid Fork Salmon	Spr Ch					1.7	1.7	1.7	3.5	1.7		3.5	5.2
Lcmhi	Spr Ch					1.7	1.7	1.7	3.5	1.7		3.5	5.2
	Sthd												
Upper Salmon	Spr Ch					1.7	1.7	**1.7**	35	**1.7**		35	5.2
	Sum Ch	0.6	2.2	1.1	1.7	1.1	3.9	**3.3**	1'1	**2.8**	83	8'9	7.8
	Sthd	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70:5	
S. Fork Salmon	Sum Ch	0.6	2.2	1.1	1.7	1.1	3.9	3.3	1.1	2.8	8.3	8.9	7.8
	Sthd												
Panther Creek	Sum Ch	0.6	2.2	1.1	1.7	1.1	3.9	3.3	1.1	2.8	8.3	8.9	7.8
	Sthd												
Pahsimeroi	Sum Ch	0.6	2.2	1.1	1.7	1.1	3.9	3.3	1.1	2.8	8.3	8.9	7.8
	Sthd												
Tucannon	Spr Ch					5					5		
	Sthd												
Imnaba	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch												
	Sthd												
Walla Walla	Spr Ch	6								6			
	Sthd										9		
Umatilla	Spr Ch	loo	90						100		100		
	Fall Ch												
	Sthd												
John Day	Spr Ch					50							
	Sthd												
L. White Salmon	Spr Ch					517							
	Fall Ch												
White Salmon	Spr Ch	336											
	Sthd												
Klickitat	Spr Ch												
	Sthd											6	
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch												
	Sthd										2		
Entiat	Spr Ch										45		
Methow	Spr Ch					1	2	2	6	11	21	33	47
	Sum Ch												
Okanogan	Sum Ch												
Wenatchee	Spr Ch					211							
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	23	24	25	26	27	28	29	30	31	32	33	34
Grande Ronde	Spr Ch												
	Sthd	8.3	8.3	8.3	8.3	8.3							
Clear-water	Spr Ch												
	Sthd	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9				
Lower Salmon	Spr Ch	12.2	20.9	12.2	8.7	13.9	7		1.7	3.5	7	19.2	8.7
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Little Salmon	Spr Ch	12.2	20.9	12.2	8.7	13.9	7		1.7	3.5	7	19.2	8.7
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Mid Main Salmon	Spr Ch	12.2	20.9	12.2	8.7	13.9	7		1.7	3.5	7	19.2	8.7
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Mid Fork Salmon	Spr Ch	12.2	20.9	12.2	8.7	13.9	**7**		1.7	3.5	7	19.2	**8.7**
Lemhi	Spr Ch	12.2	20.9	12.2	8.7	13.9	**7**		1.7	3.5	7	19.2	**8.7**
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Upper Salmon	Spr Ch	12.2	20.9	12.2	8.7	13.9			**1.7**	3.5	7	19.2	**8.7**
	Sum Ch	5	5.5	10.5	5	8.9	7.72	2.2	**2.8**	**2.8**	1.1	3.9	**3.3**
	Sthd												
S. Fork Salmon	Sum Ch	5	5.5	10.5	5	8.9	7.2	2.2	2.8	2.8	1.1	3.9	3.3
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Panther Creek	Sum Ch	5	5.5	10.5	5	8.9	7.2	2.2	2.8	2.8	1.1	3.9	3.3
	Stbd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Pahsimeroi	Sum Ch	5	5.5	10.5	5	8.9	7.2	2.2	2.8	2.8	1.1	3.9	3.3
	Sthd	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7			
Tucannon	Spr Ch												
	Sthd								6				
Imnaha	Spr Ch												
Deschutes	Spr Ch								25				
	Fall Ch												
	Sthd												
Walla Walla	Spr Ch												
	Sthd								9				
Umatilla	Spr Ch												
	Fall Ch												
	Stbd												
John Day	Spr Ch								50				
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Stbd												
Klickitat	Spr Ch								2				
	Sthd								9				
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch								3				
	Sthd								4				
Entiat	Spr Ch												
Methow	Spr Ch	62	21	22	18	15	17	21	39	41	36	39	42
	Sum Ch												
Okanogan	Sum Ch												
Wenatchee	Spr Ch								211				
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	35	36	37	38	39	40	41	42	43	44	45	46
Grande Ronde	Spr Ch												
	Sthd												
Cleat-water	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
	Stbd												
Little Salmon	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
	Stbd												
Mid Main Salmon	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
	Sthd												
Mid Fork Salmon	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
Lemhi	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
	Stbd												
Upper Salmon	Spr Ch	17.4	8.7	13.9	8.7	15.7	26.1	15.7	26.1	22.6	22.6	19.2	5.2
	Sum Ch	2.2	3.9	1.1	3.9	4.4	7.8	7.8	2.2	3.9	3.3	3.3	2.8
	Sthd												
S. Fork Salmon	Sum Ch	2.2	3.9	1.1	3.9	4.4	7.8	7.8	2.2	3.9	3.3	3.3	2.8
	Sthd												
Panther Creek	Sum Ch	2.2	3.9	1.1	3.9	4.4	7.8	7.8	2.2	3.9	3.3	3.3	2.8
	Sthd												
Pahsimeroi	Sum Ch	2.2	3.9	1.1	3.9	4.4	7.8	7.8	2.2	3.9	3.3	3.3	2.8
	Sthd												
Tucannon	Spr Ch						5					5	
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch											25	
	Fall Ch												
	Sthd												
Walla Walla	Spr Ch		6										7
	Sthd						9						
Umatilla	Spr Ch												
	Fall Ch					552					552		
	Sthd						15						
John Day	Spr Ch											50	
	Sthd											150	
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd						12						
Klickitat	Spr Ch											2	
	Sthd						6						
Hood	Spr Ch						32						
	Fall Ch												
	Sthd						12						
Wind	Spr Ch											6	
	Sthd						2						
Entiat	Spr Ch						55						
Methow	Spr Ch	38	28	25	22	25	25	27	14	21	30	27	16
	Sum Ch												
Okanogan	Sum Ch												
Wenatchee	Spr Ch											211	
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	Day* 47	48	49	50	51	52	53	54	55	56	57	58
Grande Ronde	Spr Ch												
	Sthd												
Clear-water	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
	Sthd												
Little Salmon	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
	Sthd												
Mid Main Salmon	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
	Sthd												
Mid Fork Salmon	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
Lemhi	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
	Sthd												
Upper Sahnon	Spr Ch	12.2	10.5	13.9	5.2	5.2	5.2	8.7	12.2	10.5	8.7	5.2	8.7
	Sum Ch	1.1	1.1	0.6	1.1	1.1		0.6	1.1		1.1	1.1	1.7
	Sthd												
S. Fork Salmon	Sum Ch	1.1	1.1	0.6	1.1	1.1		0.6	1.1		1.1	1.1	1.7
	Sthd												
Panther Creek	Sum Ch	1.1	1.1	0.6	1.1	1.1		0.6	1.1		1.1	1.1	1.7
	Sthd												
Pahsimeroi	Sum Ch	1.1	1.1	0.6	1.1	1.1		0.6	1.1		1.1	1.1	1.7
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Descbutes	Spr Ch												
	Fall Ch												
	Sthd									100			
Walla Walla	Spr Ch										7		
	Sthd												
Umatilla	Spr Ch												
	Fall Ch			553				553					553
	Sthd										15		
John Day	Spr Ch												
	Sthd										150		
L. White Salmon	Spr Ch							830		830			
	Fall Ch												
White Sahnon	Spr Ch												
	Sthd												
Khckitat	Spr Ch												
	Sthd				3								
Hood	Spr Ch				32								
	Fall Ch		3804										
	Sthd												
Wind	Spr Ch												
	Sthd				2								
Entiat	Spr Ch				30								
Methow	Spr Ch	18	15	25	16	31	32	12	9	4	2		
	Sum Ch												
Okanogan	Sum Ch												
Wenatchee	Spr Ch												
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	Day* 59	60	61	62	63	64	65	66	67	68	69	70
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
	Sthd												
Little Salmon	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
	Sthd												
Mid Main Salmon	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
	Sthd												
Mid Fork Salmon	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
Lemhi	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
	Sthd												
Upper Salmon	Spr Ch	10.5	13.9	15.7	10.5	5.2	7	5.2	7	15.7	8.7	22.6	24.4
	Sum Ch	1.1			1.1	0.6	0.6		1.7	1.7	0.6	2.2	2.2
	Sthd												
S. Fork Salmon	Sum Ch	1.1			1.1	0.6	0.6		1.7	1.7	0.6	2.2	2.2
	Sthd												
Panther Creek	Sum Ch	1.1			1.1	0.6	0.6		1.7	1.7	0.6	2.2	2.2
	Sthd												
Pahsimeroi	Sum Ch	1.1			1.1	0.6	0.6		1.7	1.7	0.6	2.2	2.2
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch		25										
	Fall Ch		90										
	Sthd												
Walla Walla	Spr Ch								6				
	Sthd												
Umatilla	Spr Ch												
	Fall Ch				553								
	Sthd												8
John Day	Spr Ch												
	Sthd							150					
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Srhd		12										
Klickitat	Spr Ch		7										
	Sthd												
Hood	Spr Ch		32										32
	Fall Ch												
	Sthd		12										
Wind	Spr Ch		8										
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch										2	2	2
Okanogan	Sum Ch										2	2	2
Wenatchee	Spr Ch												
	Sum Ch							**518**					

TABLE E.2
(continued)

Subbasin	Stock**	Day* 71	72	73	74	75	76	77	78	79	80	81	Day* 82
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
	Sthd												
Little Salmon	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
	Sthd												
Mid Main Salmon	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
	Sthd												
Mid Fork Salmon	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
Lemhi	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
	Sthd												
Upper Salmon	Spr Ch	19.2	10.5	26.1	12.2	8.7	20.9	12.2	17.4	5.2	13.9	8.7	5.2
	Sum Ch		1.7	3.3	1.1	1.7	1.7		0.6	1.7	2.8	0.6	1.1
	Sthd												
S. Fork Salmon	Sum Ch		1.7	3.3	1.1	1.7	1.7		0.6	1.7	2.8	0.6	1.1
	Sthd												
Panther Creek	Sum Ch		1.7	3.3	1.1	1.7	1.7		0.6	1.7	2.8	0.6	1.1
	Sthd												
Pahsimeroi	Sum Ch		1.7	3.3	1.1	1.7	1.7		0.6	1.7	2.8	0.6	1.1
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch					25							
	Fall Ch					144							
	Sthd					100							
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd												
John Day	Spr Ch												
	Sthd					150							
L. White Salmon	Spr Ch												
	Fall Ch											3064	
White Salmon	Spr Ch												
	Sthd										12		
Klickitat	Spr Ch					2							
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd										12		
Wind	Spr Ch					6							
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	5	6	6	7	7	8	8	9	9	10	10	12
Okanogan	Sum Ch	5	6	6	7	7	8	8	9	9	10	10	12
Wenatchee	Spr Ch												
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	83	84	85	86	87	88	89	90	91	92	Day* 93	94
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
	Sthd												
Little Salmon	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
	Sthd												
Mid Main Salmon	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
	Sthd												
Mid Fork Salmon	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
Lemhi	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
	Sthd												
Upper Salmon	Spr Ch	3.5	5.2	3.5	1.7		1.7	1.7	1.7	1.7			1.7
	Sum Ch	1.1	0.6			0.6							
	Sthd												
S. Fork Salmon	Sum Ch	1.1	0.6			0.6							
	Sthd												
Panther Creek	Sum Ch	1.1	0.6			0.6							
	Sthd												
Pahsimeroi	Sum Ch	1.1	0.6			0.6							
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch								144				
	Sthd												
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd			4									
John Day	Spr Ch												
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd												
Klickitat	Spr Ch								2				
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch								3				
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	13	14	15	16	17	18	19	20	21	22	23	24
Okanogan	Sum Ch	13	14	15	16	17	18	19	20	21	22	23	24
Wenatchee	Spr Ch												
	Sum Ch			**519**									

TABLE E.2
(continued)

Subbasin	Stock**	95	96	97	98	99	100	101	102	103	Day* 104	105	106
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch		1.7				5.2					1.7	
	Sthd												
Little Salmon	Spr Ch		1.7				5.2					1.7	
	Sthd												
Mid Main Salmon	Spr Ch		1.7				5.2					1.7	
	Sthd												
Mid Fork Salmon	Spr Ch		1.7				5.2					1.7	
Lemhi	Spr Ch		1.7				5.2					1.7	
	Sthd												
Upper Salmon	Spr Ch		1.7				5.2					1.7	
	Sum Ch										0.6		
	Sthd												
S. Fork Salmon	Sum Ch										0.6		
	Sthd												
Panther Creek	Sum Ch										0.6		
	Sthd												
Pahsimeroi	Sum Ch										0.6		
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch												
	Sthd												
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd												
John Day	Spr Ch												
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd												
Klickitat	Spr Ch												
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch												
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	25	25	26	26	27	27	28	28	28	29	29	29
Okanogan	Sum Ch	25	25	26	26	27	27	28	28	28	29	29	29
Wenatchee	Spr Ch												
	Sum Ch						**519**						

TABLE E.2
(continued)

Subbasin	Stock**	107	108	109	110	111	112	113	114	Day* 115	116	117	118
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch							1.7					
	Sthd												
Little Salmon	Spr Ch												
	Sthd												
Mid Main Salmon	Spr Ch												
	Sthd												
Mid Fork Salmon	Spr Ch												
Lemhi	Spr Ch												
	Sthd												
Upper Salmon	Spr Ch												
	Sum Ch				0.6								
	Sthd												
S. Fork Salmon	Sum Ch				0.6								
	Sthd												
Panther Creek	Sum Ch				0.6								
	Sthd												
Pahsimeroi	Sum Ch				0.6								
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch									144			
	Sthd												
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd												
John Day	Spr Ch												
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd												
Klickitat	Spr Ch												
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch												
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	30	29	29	29	28	28	28	27	26	25	2.4	23
Okanogan	Sum Ch	30	29	29	29	28	28	28	27	26	25	24	23
Wenatchee	Spr Ch												
	Sum Ch									519			

TABLE E.2
(continued)

Subbasin	Stock**	119	120	121	122	123	124	125	Day* 126	127	128	129	130
Grande Ronde	Spr Ch												
	Sthd												
Cleat-water	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch												
	Sthd												
Little Salmon	Spr Ch												
	Sthd												
Mid Main Salmon	Spr Ch												
	Sthd												
Mid Fork Salmon	Spr Ch												
Lemhi	Spr Ch												
	Sthd												
Upper Salmon	Spr Ch												
	Sum Ch												
	Sthd												
S. Fork Salmon	Sum Ch												
	Sthd												
Panther Creek	Sum Ch												
	Sthd												
Pahsimeroi	Sum Ch												
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch												144
	Sthd												
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd												
John Day	Spr Ch												
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd												
Klickitat	Spr Ch												
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch												
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	22	21	20	19	19	18	17	16	15	14	13	12
Okanogan	Sum Ch	22	21	20	19	19	18	17	16	15	14	13	12
Wenatchee	Spr Ch												
	Sum Ch												

TABLE E.2
(continued)

Subbasin	Stock**	131	132	133	134	135	136	Day* 137	138	139	140	141	142
Grande Ronde	Spr Ch												
	Sthd												
Clearwater	Spr Ch												
	Sthd												
Lower Salmon	Spr Ch												
	Sthd												
Little Salmon	Spr Ch												
	Sthd												
Mid Main Salmon	Spr Ch												
	Sthd												
Mid Fork Salmon	Spr Ch												
Lemhi	Spr Ch												
	Sthd												
Upper Salmon	Spr Ch												
	Sum Ch												
	Sthd												
S. Fork Salmon	Sum Ch												
	Sthd												
Panther Creek	Sum Ch												
	Sthd												
Pahsimeroi	Sum Ch												
	Sthd												
Tucannon	Spr Ch												
	Sthd												
Imnaha	Spr Ch												
Deschutes	Spr Ch												
	Fall Ch												
	Sthd												
Walla Walla	Spr Ch												
	Sthd												
Umatilla	Spr Ch												
	Fall Ch												
	Sthd												
John Day	Spr Ch												
	Sthd												
L. White Salmon	Spr Ch												
	Fall Ch												
White Salmon	Spr Ch												
	Sthd												
Klickitat	Spr Ch												
	Sthd												
Hood	Spr Ch												
	Fall Ch												
	Sthd												
Wind	Spr Ch												
	Sthd												
Entiat	Spr Ch												
Methow	Spr Ch												
	Sum Ch	11	10	9	8	7	6	5	4	3	2	1	
Okanogan	Sum Ch	11	10	9	8	7	6	5	4	3	2	1	
Wenatchee	Spr Ch												
	Sum Ch					518							

TABLE E.2
(continued)

Subbasin	Stock**	143	144	145	146	147	148	149	150	151	152
							Day*				
Grande Ronde	Spr Ch										
	Sthd										
Clearwater	Spr Ch										
	Sthd										
Lower Salmon	Spr Ch										
	Sthd										
Little Salmon	Spr Ch										
	Sthd										
Mid Main Salmon	Spr Ch										
	Sthd										
Mid Fork Salmon	Spr Ch										
Lemhi	Spr Ch										
	Sthd										
Upper Salmon	Spr Ch										
	Sum Ch										
	Sthd										
S. Fork Salmon	Sum Ch										
	Sthd										
Panther Creek	Sum Ch										
	Sthd										
Pahsimeroi	Sum Ch										
	Sthd										
Tucannon	Spr Ch										
	Sthd										
Jmnaha	Spr Ch										
Deschutes	Spr Ch										
	Fall Ch			90							
	Sthd										
Walla Walla	Spr Ch										
	Sthd										
Umatilla	Spr Ch										
	Fall Ch										
	Sthd										
John Day	Spr Ch										
	Sthd										
L. White Salmon	Spr Ch										
	Fall Ch										
White Salmon	Spr Ch										
	Sthd										
Klickitat	Spr Ch										
	Sthd										
Hood	Spr Ch										
	Fall Ch										
	Sthd										
Wind	Spr Ch										
	Sthd										
Entiat	Spr Ch										
Metbow	Spr Ch										
	Sum Ch										
Okanogan	Sum Ch										
Wenatchee	Spr Ch										
	Sum Ch										

Notes:
* migration is April 1 (Day 1) to August 30 (Day 152)
** spring chinook (Spr Ch), summer chinook (Sum Ch), fall chinook (Fall Ch), steelhead (Sthd)
*** point of entry of stock to mainstem pool, in miles above closest downstream dam
Source **Fish Passage Center, 1991 (edited)**

GLOSSARY

Activity   A variable whose value is set by the optimization model as in selecting the least cost strategy (e.g., whether or not to use a particular passage strategy, or at what rate to harvest a particular stock). Also known as a decision variable.

Adaptive Management   an approach to reducing uncertainty by using management actions as experiments which provide information about the system. Such information is then used for more efficient management.

Adult   for salmonids, a fish that is sexually mature.

Alevin   a newly hatched salmon or trout prior to absorption of the yolk sac.

Anadromous   fish which spawn in fresh water but s spend a significant portion of their life in the ocean.

Annualized cost   cost of a capital investment (e.g., a hatchery or bypass facility) spread out over the useful life of the facility. Includes the interest expense required to finance the investment.

Beverton-Holt curve   a spawner-recruit relationship characterized by a curve depicting the number of recruits increasing to an asymptotic limit as the number of spawners increase.

BPA   Bonneville Power Administration

Brood year   the year in which a fish begins life.

Bypass   activities or structures designed to guide smolts around turbines at run-of-river dams

C/E   Cost-effectiveness. See Chapter 2.

CBFWA   Columbia Basin Fish and Wildlife Authority. An umbrella organization for state and tribal fisheries management agencies.

COE   U.S Army Corps of Engineers

Coefficient Used to define the relationship between activities and constraints. Always set to - 1, 0, or +l in the current problem.

Cohort fish offspring of the same brood year.

Collection facilities structures to hold bypassed smolts in preparation for transportation downstream in trucks or barges

constraint An equation or expression used to establish limits on what the optimization can do.

Council Northwest Power Planning Council

CRiSP Columbia River Fish Passage Model. Used to evaluate the effects of smolt passage strategies.

DLCM Deterministic Life Cycle Model. See Chapter 3 and Appendix A.

Escapement the number of adults which survive to reach the spawning grounds.

Fullback a situation in which fish which have ascended a dam are swept back downstream of the dam.

Fecundity usually refers to the number of eggs produced per female.

Fingerling a young or small fsh, larger and more developed than a fry.

Fishery the complex of interactions among a fish population(s), the people which exploit them, and the environment.

Fry young, recently hatched fish generally capable of feeding only on microorganisms.

Heuristic model a model which serves primarily as an experimental device for exploring modeling techniques.

Hierarchy an arrangement of objects into a graded series based on the relationships among the objects themselves.

Jack a precocious male salmon or steelhead trout, generally fish that have matures at least one year earlier than most members of the same cohort.

Juvenile fish that are not sexually mature.

Juvenile prod&ion	generally used in this text to refer to the production of smolts.
Life stanza	a distinct period in the salmonid life cycle.
Mainstem	Snake or Columbia rivers, as distinct from subbasins or tributaries.
Management Action	Smallest single management option that will have a unique effect on a biological parameter; e.g., add screens at a run-of river dam, or add rearing capacity at a hatchery.
Mass-Balance Constraint	Used to ensure internal consistency in the optimization, so that all stocks in the system use the same downstream passage strategy, or all stocks in the same subbasin use the same propagation strategy.
Module	a simulation model which can operate independently or in tandem with other modules.
Non-terminal harvest	any harvest occurring outside the subbasin (e.g., ocean harvest or mainstem river harvest).
NPPC	Northwest Power Planning Council
Objective Function	Function that the optimization tries to minimize, within bounds established by a set of constraints.
Outplanting	placing fry or fingerling into areas for rearing to supplement or replace natural reproduction.
Parr	juvenile anadromous salmonids which normally reside for a year or more in fresh water and are not capable of tolerating saline water. May refer to steelhead trout, coho, sockeye, or chinook salmon.
Passage Strategy	Combination of passage actions; will affect all stocks in the system simultaneously; can only use one passage strategy for the entire system.
Pre-smolt	similar to Parr.

Propagation	spawning and rearing, in either hatcheries or in natural settings.
Propagation Strategy	Combination of propagation actions; will affect all stocks in a given subbasin simultaneously. Exactly one propagation strategy per subbasin.
Propagation/Terminal Harvest/Passage Alternative	Combination of a system-wide passage strategy, subbasin-specific propagation strategy, and stock- specific terminal harvest rate, for a single stock. The alternative defines all the information necessary to calculate the adults produced for a given stock, Generated by the deterministic simulation model.
Recruit	fish which are newly joined with a population under consideration.
Recruitment	the addition of new members to the aggregate population under consideration.
Redd	the spawning nest of salmonids; usually a scooped depression in clean gravel in which eggs are deposited and buried.
Resolution	the ability to distinguish between two separate objects.
RHS	Abbreviation for "Right Hand Side." Determines how much of each activity must be undertaken. In the current problem, always set to zero or one.
Ricker curve	a spawner-recruit relationship characterized by a dome shaped curve.
Run size	as defined by the Council, the total number of fish returning to the mouth of the Columbia plus ocean harvest.
Run year	**the year in which a fish returns to spawn as an adult.**
Run-of-river dam	dams designed with little or no storage capacity
Runsize	as used here, the sum of subbasin escapement and non-terminal harvest for a stock.
Scope	the relative temporal and spatial extent of the system under consideration.

Shaker

a fish which is smaller than the legal size limit for harvest but which is susceptible to the angling gear.

Smolt

a juvenile salmonid which is physiologically prepared to out migrate from fresh saline waters.

Smoltification

the physiological process which prepares an anadromous fsh for life in saline waters.

Spawner-recruit curve

the relationship between some measure of biomass present in spawning adults and the biomass of recruits derived from the spawning adults.

Stock

a population of fish which remain genetically, spatially, or behaviorally separated from other populations and which shares a common life among its members.

Storage dam

used to store water for irrigation and power production

System-Wide Least-Cost Strategy

The system-wide strategy which meets a set of biological objectives at the lowest possible cost of subbasin-specific propagation strategies and one passage strategy. Generated by the linear programming model, using alternatives generated by the deterministic simulation model.

System-Wide Strategy

Combination of propagation/terminal harvest/passage alternatives for all stocks in the model. All stocks use the same passage strategy and all stocks within a given subbasin use the same propagation strategy, although different stocks in the same subbasin may have different terminal harvest rates.

Systems analysis

a body of theory and techniques used to understand complex systems, usually involving advanced mathematical and statistical techniques and the use of computers.

Systems Analysis Model (SAM)

hydropower model used by BPA and others to evaluate the costs and power production implications of hydrosystem and thermal power operations

Tableau   Computerized representation of the objective function, activities, constraints, coefficients, and RHS values.

TBR   Transportation Benefit Ratio, the ratio of transported fish returning to a sampling site to untransported fish returning to the same site.

Terminal harvest   harvest occurring within a subbasin or just prior to adults returning to spawn at a hatchery

Water Budget   a program to provide addition instream flows during the period of peak outmigration to increase the travel rate of migrating smolts.

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